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WOUND HEALING, KEEPING QUALITY, AND COMPOSITIONAL CHANGES DURING CURING AND STORAGE OF SWEET POTATOES¹

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THE STORAGE of sweet-potato roots (*Ipomea batatas*) is essential to both the production and the utilization of this vegetable. Since the major portion of the California crop is harvested during late summer and early fall, storage is required for a supply at other seasons. Furthermore, propagation of the crop depends upon the storage of seed roots from a previous crop.

Storage in California usually takes place on the farm with methods that are relatively crude and that do not follow recommendations worked out in other production areas (Minges and Morris, 1953). For short-time storage the roots are commonly held in piles in the field. Structures used for longer storage periods vary greatly, ranging from well-built structures to space provided in basements, barns, and other farm buildings. Many of the storages that have been built specifically for sweet potatoes are termed cellars and are noninsulated wooden structures built partly below the ground level. The mild climate in the production areas of California has undoubtedly favored the use of structures and methods untenable in many other sweet-potato-producing areas.

Storage Requirements of Sweet Potatoes

Under favorable storage conditions, sweet potatoes may be held for six months or more. Deterioration during storage is attributable to many factors. In addition to the unavoidable metabolic changes, water loss, decay, sprouting, and chilling injury can be important. The environmental factors establishing the nature and extent of deterioration are temperature, relative humidity, mechanical injury, and the presence of rot-producing organisms.

A sweet-potato root is covered by a periderm that is effective in retarding water loss and acts as a barrier against infection. At time of harvest this skin is unavoidably broken and removed in varying degrees. The resulting wounds will heal by suberization and development of a wound periderm if environ-

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mental conditions are favorable (Artschwager and Starrett, 1931). Experiments have shown that healing will proceed rapidly at a temperature of 85°F or slightly above and a relative humidity of 85 per cent or above, and that healed wounds are quite resistant to infection (Lauritzen, 1935). The commercial procedure of holding potatoes under these conditions for a period of 10 to 14 days is known as curing and is commonly practiced in sweet-potato production areas other than California (Lutz and Simons, 1948). The purpose of curing is not to remove moisture, although such an opinion is common among commercial handlers of the crop and is also expressed in recent horticultural literature (Thompson, 1949; Brown and Hutchison, 1949; Work, 1945; Watts and Watts, 1939). It has been shown that ventilation during commercial curing is neither essential nor desirable except to control temperature or condensation of water.

After curing, the storage temperature should be maintained in the range of 55° to 60°F. Sweet potatoes are subject to chilling injury if exposed to temperatures of 50°F and below (Lauritzen, 1931; Kimbrough and Bell, 1942). The extent of injury is dependent upon the temperature and duration of holding and on the variety and maturity of the crop. The symptoms produced by chilling are surface pitting, increased susceptibility to decay, loss of table quality, and loss of sprouting ability. Curing will reduce subsequent susceptibility to chilling injury (Lutz, 1945).

Previous Storage Investigations in California

Because storage practices in California appeared to be inadequate and did not conform with the recommended practices of other areas, a three-year storage investigation was conducted by Long and Porter (1940) from 1932 to 1935. The primary purpose of their investigation was to compare the common cellar storages with a heated storage. Two structures were erected at Davis—one a small version of the storage houses in common use and the other an aboveground house with insulated walls and roof and provided with electric heaters. At the time of this work the role of curing and the limitations imposed by environmental factors were not as clearly understood as they are today. Although the conditions maintained in the heated house were not optimum, the results pointed clearly to the value of a heated house where both desirable curing and storage temperatures could be maintained. This study also led to the conclusion that box storage would be preferable to bulk, and that movement of the crop directly from the field to the storage house would be better than temporary holding in piles in the field.

The Present Study

Interest in California sweet-potato storage problems was renewed in the summer of 1943. The construction of new storage houses by two of the leading growers pointed up a lack of information, since these houses incorporated many of the objectionable features of the existing structures and curing was not being practiced.

An investigation of temperatures in commercial storage houses and field piles was carried out during the 1943-44 season. Many growers believed that

sweet potatoes should be "cured" in field piles before storage. Temperatures observed in two field piles were not in a range conducive to wound healing but indicated that these piles could provide protection against serious chilling for a limited holding period. Furthermore, temperatures observed in storage houses were not considered to be favorable to curing, and there appeared to be some danger of chilling during the winter.

As a result of these observations, a study of storage losses as affected by curing procedures together with a study of temperatures existing in commercial farm storages was undertaken. Since the role of curing is known to depend largely on wound healing, an anatomical study was made of the natural periderm and the wound periderm existing after various curing treatments.

FARM STORAGE TESTS

Materials and Methods

Five tests were conducted in farm storages located in sweet-potato production areas of Merced and San Joaquin counties during the period from 1944 to 1948. All tests followed a similar plan—the potatoes were subjected to prestorage treatments and then held to evaluate the effect of these treatments upon storage behavior. Included in the tests were the Porto Rico, Yellow Jersey, and Hawaiian varieties. Three prestorage treatments, referred to here as curing treatments, included a field-pile cure, a storage-house cure, and a warm-house cure. These are described below. Table 1 gives for each of the tests the coöoperator and area, the varieties included, the number and size of the replicates, and the dates of harvesting, curing, and termination.

Potatoes. The Porto Rico, which is commercially the most important variety in California, was included in all five tests. The Yellow Jersey, second in commercial importance, and the Hawaiian, which is of relatively minor importance, were each studied in four of the five tests. Production of the Hawaiian variety is probably confined to the Central Valley of California where it has been grown for many years and is noted for its excellent keeping qualities. The variety appears to belong to the Ticotea group in Thompson's classification (Thompson and Beattie, 1922). Minges and Morris (1953) give a more complete discussion of these varieties in California.

The potatoes for each test were grown on or near the farm of the coöoperator. In most cases the roots were dug with a mechanical potato digger, and the tests were usually started on the day of digging or the day following. Within any one test, care was exercised to have all the replicates representing any one variety strictly comparable at the outset. Roots of unmarketable size and those showing severe sprouting, mechanical injury, cracking, or decay were excluded. Sorting was strictest for the first test; in later tests tolerances conformed more closely to commercial practice.

In each test, each curing treatment was represented by 4 to 7 replicates, as indicated in table 1. A replicate consisted of approximately 50 pounds of roots contained in either a bushel basket (lidded) or a box (unlidded).

Curing Treatments. The three curing treatments included a warm-temperature cure and two common commercial practices. One of the com-

mercial practices was to place the potatoes in field piles for a short period between harvest and transfer to storage. Growers refer to this as field-pile curing and many consider it desirable. The second commercial practice consisted of moving the potatoes directly from the field to the storage house without any effort or intent to provide conditions favorable to curing. All sweet potatoes in these tests received one of these treatments prior to storage. For convenience, the term "cure" will be applied to all three prestorage treatments, whether or not that particular treatment was favorable to wound healing.

For the *field-pile* cure, potatoes were placed directly on the soil in a rectangular pile with sloping sides. The pile measured 2 to 3 feet wide by 4 to 6 feet long at the base and was 1½ to 2 feet high. The pile was covered with wrapping paper, with an opening at each end for ventilation, and over the whole was placed a 5- to 6-inch-thick layer of fresh potato vines. The sweet potatoes were removed from their containers and held in bulk during this treatment. At the end of the treatment the decayed roots were sorted out and the replicates replaced in containers for the storage period.

With the *storage-house* cure, the packaged replicates were placed in a storage house that was being filled with a commercial crop of potatoes. The growers made no effort to provide ideal curing conditions during this early storage period. This treatment simulated the common practice of moving the potatoes directly from the field to storage, except that commercial storage is usually in bulk rather than in containers.

In the *warm-house* cure, the temperature and humidity were kept high to provide conditions known to favor wound healing. At the outset of this work, commercial curing was not being practiced by the coöperators. In the first three tests, the replicates were held in small nonventilated rooms used for the sulfuring of dried fruits. The room was heated by electricity, and water was added to help maintain the high humidity. In the last two tests intentional curing was being practiced by the coöperator, so the warm-house cure was accomplished by using the curing conditions within a commercial storage. In these latter tests, the storage-house cure was carried out in a near-by storage in which no effort was being made to maintain good curing conditions.

Storage after Curing. After the curing treatment, all lots were placed alongside each other in a commercial storage house. Each curing treatment made up a separate stack extending to the approximate height of the potatoes of the commercial lots. These stacks were placed in or near the aisle for convenience but were in a location representing typical conditions of storage. The first three tests were conducted in a cellar-type storage where the temperature was controlled by ventilation. The houses used for tests 4 and 5 were equipped with furnaces to supply heat during the cure and during periods of low temperature. In all cases the coöoperator made an effort to keep the minimum temperature above 50°F.

Temperature and Humidity Records. Thermographs were maintained with the experimental lots during the curing period and throughout most of the storage. The thermographs were placed in close proximity to the experimental lots. In the field piles, a small 30-day thermograph was buried

amongst the potatoes. The records of relative humidity were undesirably limited because of lack of recording hygrometers.

Determination of Storage Losses. To determine *weight loss*, weights were taken at the outset, after the curing period, and at the end of the storage period in all tests. In some of the tests, additional weighings were made during the storage period. The losses thus measured were expressed as percentages of the total original weight. These losses include the loss of water (transpiration) plus the loss of dry weight (respiration) by both the sound and the decayed roots. Even though this includes the weight loss of roots showing decay, it is assumed to be the best measure of the effectiveness of the curing treatment in reducing rate of water loss. When roots showing decay were removed from the replicate previous to the end of the test, appropriate corrections were made in calculating the weight loss.

Total loss was determined by weighing salable roots at the end of the storage period. This loss was expressed as a percentage of the original weight. This figure combines all losses and gives the best criterion of the over-all effect of the curing treatment on weight loss and decay.

In all treatments potatoes showing decay were weighed at the end of the storage period. Roots showing decay were removed from the top layers of the replicates at each weighing, and for the field-pile cure the entire lot was sorted when the potatoes were transferred from the field pile to the storage house. As noted above, appropriate corrections were applied to the calculation of weight losses when sorting occurred before termination of the test.

The weight-loss and total-loss data were reduced by analyses of variance in which percentages were used since all samples were of approximately the same size.

The *rot loss* was arrived at by subtracting the weight loss from the total loss. This, then, represents the loss that can be attributed to decay *per se*. This loss was arrived at by subtraction rather than by direct weighing of rotted potatoes because of the small amounts of decay involved in some lots, because of some sorting during the experiment, and as a matter of convenience. Weight loss and rot loss were the only possible components of total loss except for a negligible amount of rodent injury in a few replicates.

Compositional and Quality Changes. Sugar analyses following AOAC methods (Association of Official Agricultural Chemists, 1945) were made on samples taken before and after curing and during the storage period in tests 1 and 2. Duplicate 100-gram samples were derived from lots of 20 potatoes comparable to those entering the storage-loss tests. Dry-weight changes were also followed.

In tests 1 and 2, sugars were also estimated by use of a Zeiss hand refractometer calibrated in percentage of sucrose. These readings were made on juice expressed from potatoes comparable to those used for the chemical methods.

Taste tests by a group of five to seven individuals rating boiled samples as to *general quality*, *sweetness*, and *moistness of flesh* were carried out in test 1. The first two attributes were scored according to an arbitrary scale of 1 to 9, the larger values representing the better quality.

TABLE I
 FARM STORAGE TESTS: COOPERATORS, VARIETIES, NUMBER OF REPLICATIONS,
 AND DATES OF HARVEST, CURING, AND STORAGE
 Three curing treatments were applied to each variety included in each test

Test no.	Cooperator and location	Varieties used	Replicates in each of the three cures	Date harvested	Curing period	End of storage period
1	E. B. Wood (Merced Co.)	Porto Rico	4 (bushels)	Nov. 7, 1944	Nov. 8-Nov. 21	March 2, 1945
		Yellow Jersey		Nov. 6, 1944	Nov. 8-Nov. 21	March 2, 1945
		Hawaiian		Nov. 8, 1944	Nov. 8-Nov. 21	April 18, 1945
2	E. B. Wood (Merced Co.)	Porto Rico	5 (bushels)	Oct. 23, 1945	Oct. 24-Nov. 5	March 18, 1946
		Yellow Jersey		Oct. 23, 1945	Oct. 24-Nov. 5	Feb. 16, 1946
		Hawaiian		Oct. 22-23, 1945	Oct. 24-Nov. 5	May 6, 1946
3	E. B. Wood (Merced Co.)	Porto Rico	5 (bushels)	Oct. 24, 1946	Oct. 24-Nov. 6	April 2, 1947
		Yellow Jersey		Oct. 24, 1946	Oct. 24-Nov. 6	April 2, 1947
		Hawaiian		Oct. 23, 1946	Oct. 24-Nov. 6	April 2, 1947
4	J. G. Lawrence (Merced Co.)	Porto Rico	7 (apple boxes)	Nov. 7, 1946	Nov. 7*-Nov. 25	April 2, 1947
		Hawaiian		Oct. 31, 1946	Oct. 31*-Nov. 25	April 2, 1947
5	Gus Schmidt (San Joaquin Co.)	Porto Rico	6 (apple boxes)	Oct. 9, 1947	Oct. 9-Oct. 23	Jan. 29, 1948
		Yellow Jersey		Oct. 9, 1947	Oct. 9-Oct. 23	Jan. 29, 1948

* Heat not started in Warm House until Nov. 8.

Results

Temperature and Humidity during Storage. The average daily temperatures are summarized in figure 1, and the limited observations on relative humidity are discussed below.

In *test 1* temperatures in the warm house were in a range conducive to wound healing, while those in the field pile were too low for rapid wound healing. In fact, during the second week the latter averaged below the range recommended for storage. Thus, these potatoes, especially those toward the exterior of the pile, were chilled slightly. Temperatures in the storage house were favorable for good storage but not for rapid wound healing. The storage temperatures following the curing treatments were mostly favorable.

No relative-humidity records were obtained during the curing or early storage period of *test 1*. Recordings in the storage house started in late December ranged from about 70 to 90 per cent up to mid-February, after which they dropped, averaging between 50 and 70 per cent.

In *test 2*, temperatures in the warm house were in a desirable range during the first week of the cure but dropped somewhat thereafter. The storage-house temperatures averaged about 65°F during the curing period. The thermograph placed in the field pile failed to record correctly, but from outdoor maxima and minima it is estimated that these temperatures averaged in the high fifties and the low sixties. The temperatures during the storage period were within a desirable range. The relative humidity was recorded only for the warm-house cure. During the first week the relative humidity ranged from about 70 to 90 per cent, and during the second week above 90 per cent.

Temperatures during the warm-house cure of *test 3* were mostly above 80°F. In both the storage house and the field pile the initial temperatures were relatively warm but dropped rapidly. The average field-pile temperature dropped to a chilling range with minima of 40°F on several nights. The relative humidity in the warm house was undesirably low during curing, starting in the range of 70 to 80 per cent and steadily dropping to a level of 30 to 40 per cent. This occurred in spite of efforts made to keep the humidities high. The temperature record for the storage period of *test 3* is not complete. Shown in figure 1 are the average temperatures to November 22. No record is available between November 22 and December 10. An incomplete record between December 11 and December 24 indicates that the average temperature of the storage-house air dropped from the middle fifties to the mid-forties during this period, and no record is available after this date.

Test 4 differed from the other tests in that the two varieties under test were subjected to different curing periods, and the Hawaiian variety was given a prolonged curing period because of delay in supplying heat for the warm-house cure (table 1). The warm-house cure for this variety was in effect a delayed cure. Before the heater was started, the temperatures fluctuated each day between the mid-forties and the mid-sixties. After heat was supplied, the temperatures averaged in the high sixties. The temperature record for the storage house is incomplete between October 31 and November 7, but the temperatures are assumed to have approximated those of the unheated warm

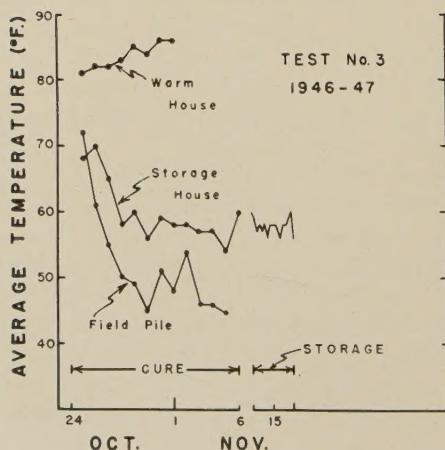
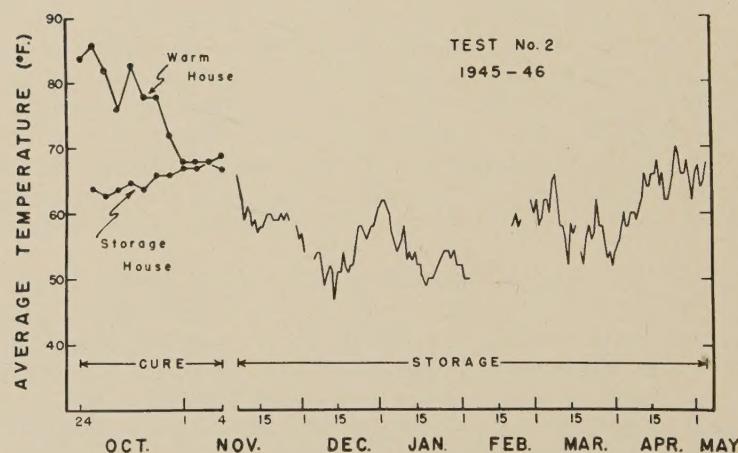
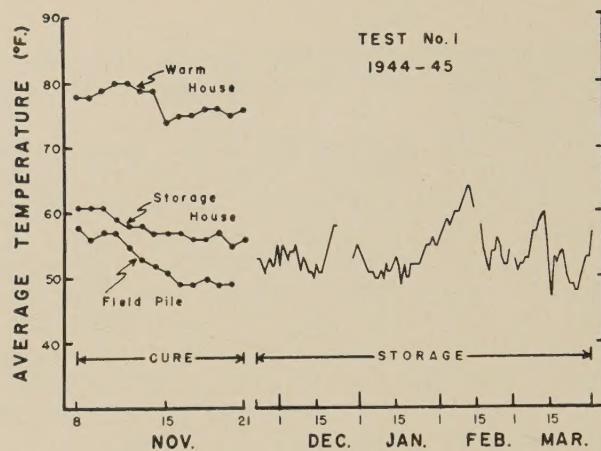


Fig. 1.
See opposite page also.

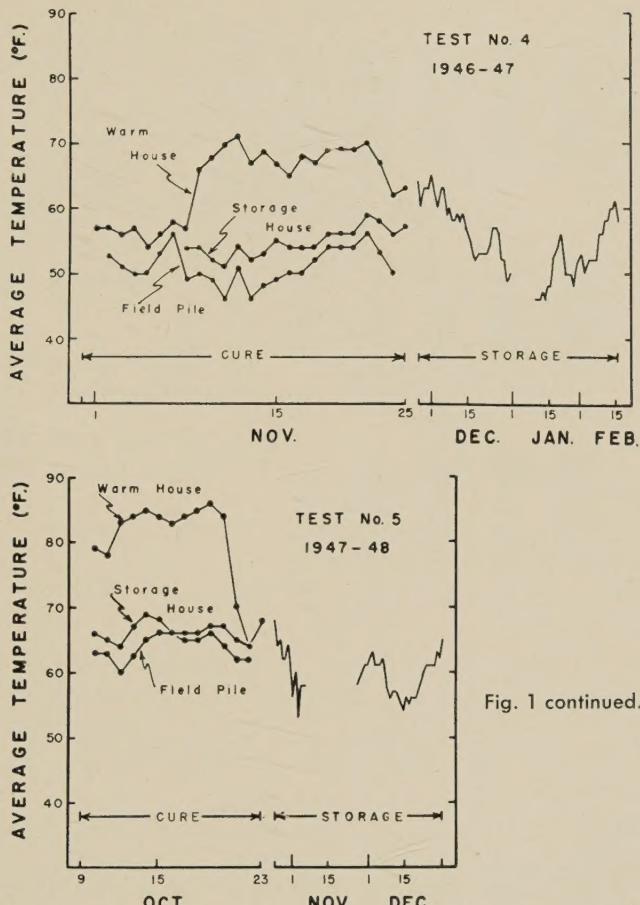


Fig. 1 continued.

Fig. 1. Average temperature (mean of the daily maximum and minimum) in degrees Fahrenheit during curing and storage for five farm-storage tests. In test 2 the thermograph failed to function in the field pile. Note that the time scale for the storage period differs from that of the curing period.

house since the two structures were similar. The field-pile temperatures were obtained for the Hawaiians only, but it can be assumed that they are also representative of the Porto Rico field pile.

During curing relative humidity was recorded only in the warm house and only after the heater was started. The humidity fluctuated widely during the first few days of heating and then rose to a fairly constant level above 80 per cent for the remainder of the curing period. Recordings of relative humidity during storage were continued until late January and indicate a fairly high level—above 90 per cent much of the time and above 70 per cent most of the time.

In test 5, the warm-house cure was carried out in a house where commercial

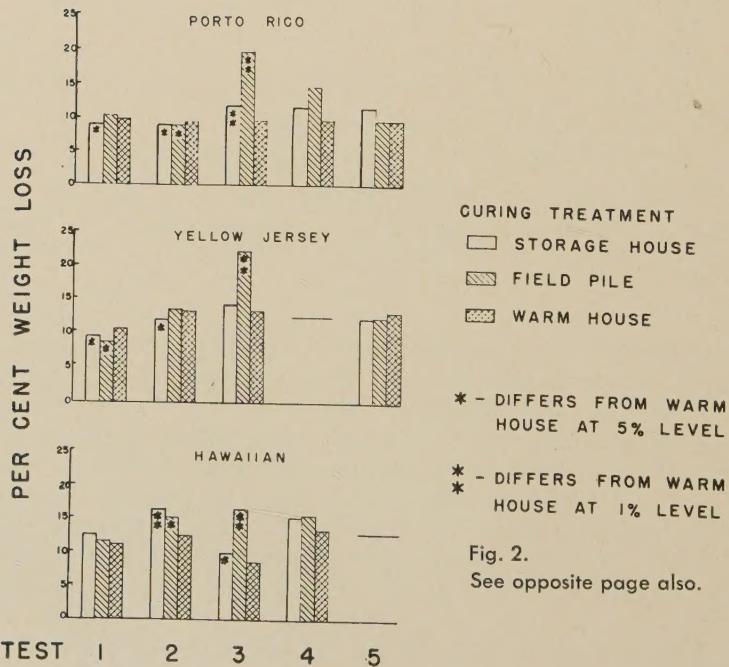
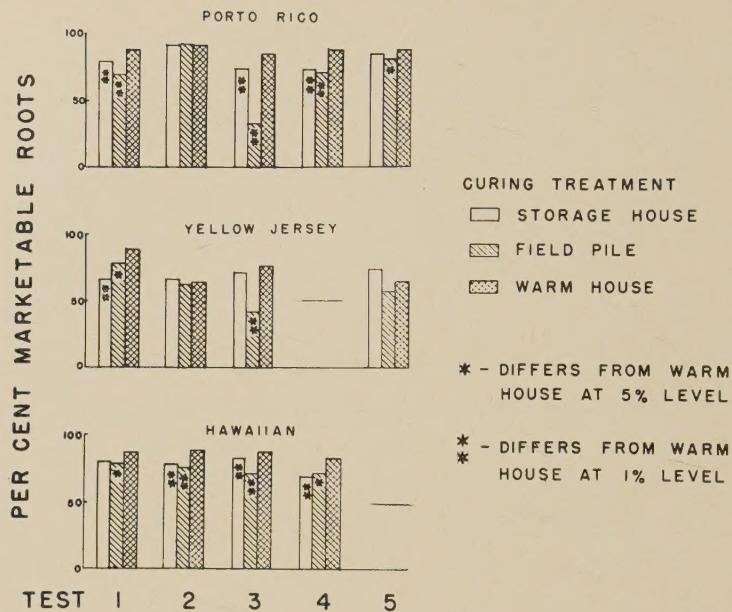


Fig. 2.
See opposite page also.

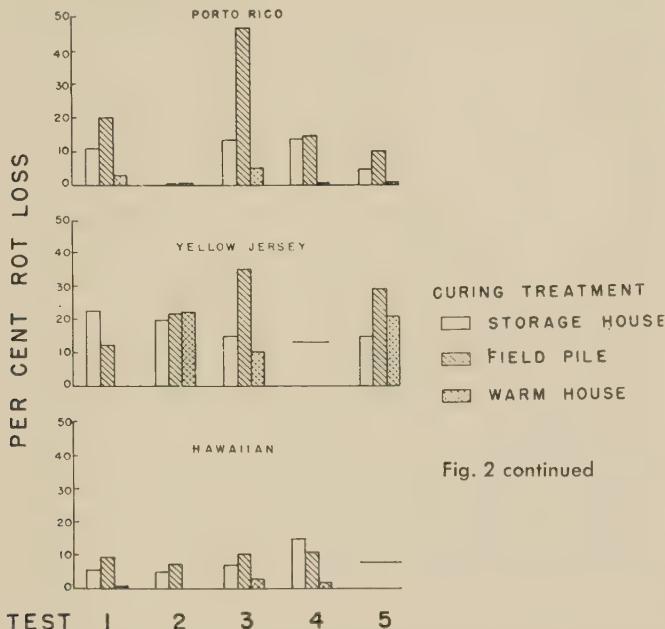


Fig. 2 continued

Fig. 2. Data on five farm-storage tests, showing percentages of marketable roots, weight loss, and rot loss at the end of the storage period. These data, based on weight changes, are expressed as percentages of the fresh weight of roots at the beginning of the tests. Weight loss includes loss of moisture and dry matter from both sound and rotted roots, and rot loss includes all losses not accounted for by weight loss.

curing was being practiced. As seen in figure 1, the cooling was begun a few days before the transfer of the other lots to this house for storage. Since this test was started early in the season, the temperatures in the field pile and the unheated storage house were relatively warm in comparison to those of other years.

The relative humidity of the warm-house cure was desirably high throughout most of the curing period, being above 80 per cent most of the time until cooling was begun and then dropping to between 50 and 70 per cent. In the unheated storage house the relative humidity fluctuated with the temperature and was in the range of 60 to 90 per cent most of the time. Records during the first two weeks of storage show that the relative humidity was usually above 70 per cent for the storage-house air.

Storage Losses. Results of the five farm storage tests are summarized in figure 2, which shows the averages of the replicates representing each of three treatments for each variety within each test.

The warm-house cure resulted, in general, in less total loss during storage than occurred following the other cures. With the Porto Rico variety, the warm-house cure gave a significantly higher percentage of weight of marketable potatoes than either the field-pile or storage-house cures in three of the tests. In test 5, the warm-house cure was significantly better than the field-pile

cure but not significantly better than the storage-house cure. Little or no difference existed between treatments in test 2.

In all four tests with the Hawaiian variety, the percentages of marketable potatoes were highest with the warm-house cure. The difference was significant in seven out of eight comparisons and highly significant in six instances.

The value of the warm-house cure was less apparent with the Yellow Jerseys. Only in one test out of four was this treatment significantly better than both of the other cures in regard to the percentage of marketable roots at the end of storage. In test 3 the difference was significant only in comparison with the field-pile cure. Significant differences did not develop in test 2 or test 5.

In no test did the warm-house cure result in significantly fewer marketable potatoes at the end of storage than the other cures. The beneficial effect, observed in most of the cases, was predominantly from a reduction in rot loss. The effect of the curing treatments on rot loss is shown in figure 2. The loss attributable to decay was the least with the warm-house cure in all tests with the Porto Rico and Hawaiian varieties with the exception of test 2, where there was no reduction with Porto Rico and where the losses due to decay were nil. With Yellow Jersey, rot loss was reduced in only two of the four tests by the warm-house cure. The Yellow Jerseys benefited less from the warm-house cure than did the other varieties, and this is thought to be due to the high incidence of black rot (*Ceratostomella fimbriata*), which apparently was not controlled by curing.

The relatively large amount of decay that followed the field-pile cure with all varieties in test 3 is probably due in part to chilling encountered during the curing period (fig. 1).

The effect of curing treatment on weight loss (that is, water loss plus respiratory loss) over the entire storage period was not consistent when all tests are considered. Only in test 3 did the warm-house cure result in a reduced weight loss for all three varieties. This reduction was significant in five of the six comparisons. The relatively large vapor-pressure deficit existing under the warm-house curing despite the relatively high humidity resulted in an accelerated rate of weight loss during the curing period. Potatoes receiving this treatment lost more weight than those from the other treatments, except in test 3 where the roots of all varieties lost weight most rapidly during the field-pile cure. The weight-loss data of test 1 are shown in figure 3, and these responses are taken as fairly typical. Even though the rate of subsequent water loss was reduced by the warm-house cure, the initial disadvantage was not often overcome. Thus, high humidity is important during the curing period to minimize weight loss as well as to promote wound healing.

Dry Matter and Sugar Changes. Changes in dry matter and sugars were determined for all varieties and curing methods in tests 1 and 2 except for the field-pile cure of test 2.

Dry weight, as percentage of fresh weight at time of sampling, shows little change from time of harvest to end of storage period, since water and dry matter were lost roughly in proportion to the amounts originally present. Dry-matter content may be expressed, however, as percentage of the initial

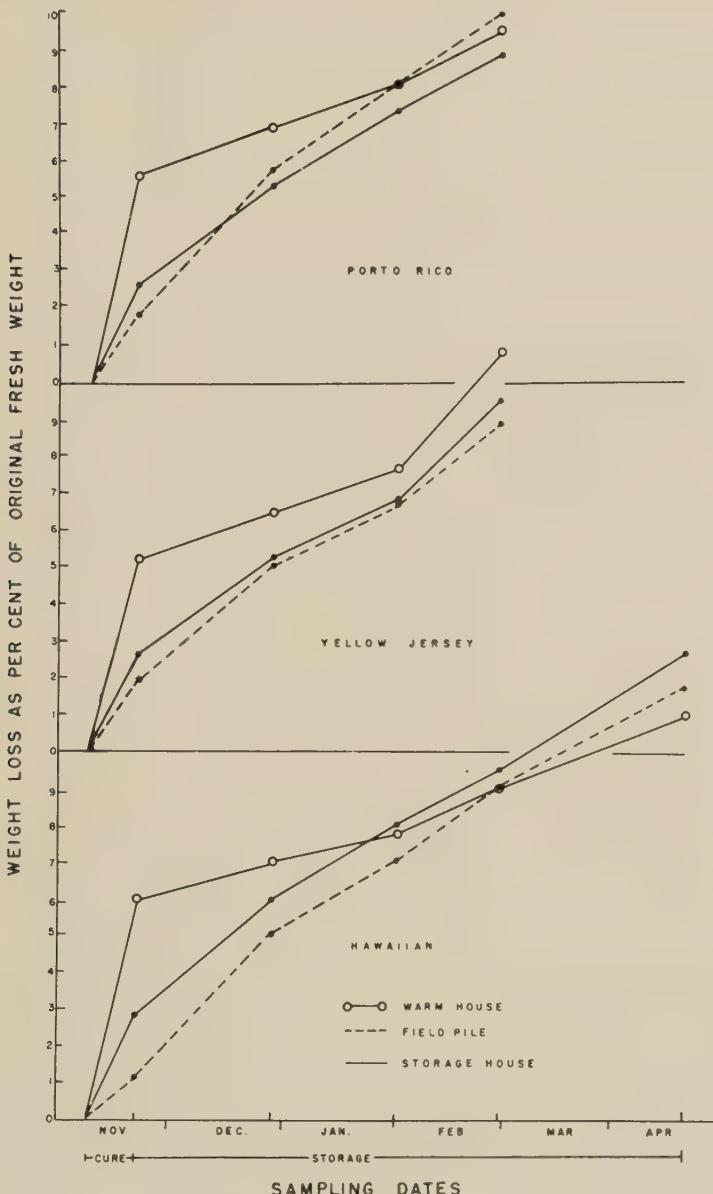


Fig. 3. Weight loss from sweet-potato roots during curing and storage expressed as percentage of original fresh weight. All treatments were stored together except during the curing period. Data from test 1.

dry-matter content of the samples. Graphs drawn on this basis are given for test 1 in figure 4. Data in this figure are given by variety—all curing methods are averaged together. Data from test 2 are in agreement with the data of figure 4 except that in the latter test the Yellow Jersey variety lost more dry matter than did the Porto Rico. In both tests, the Hawaiians lost the least dry weight, indicating a relatively low rate of metabolic activity, which is compatible with the superior keeping quality attributed to this variety.

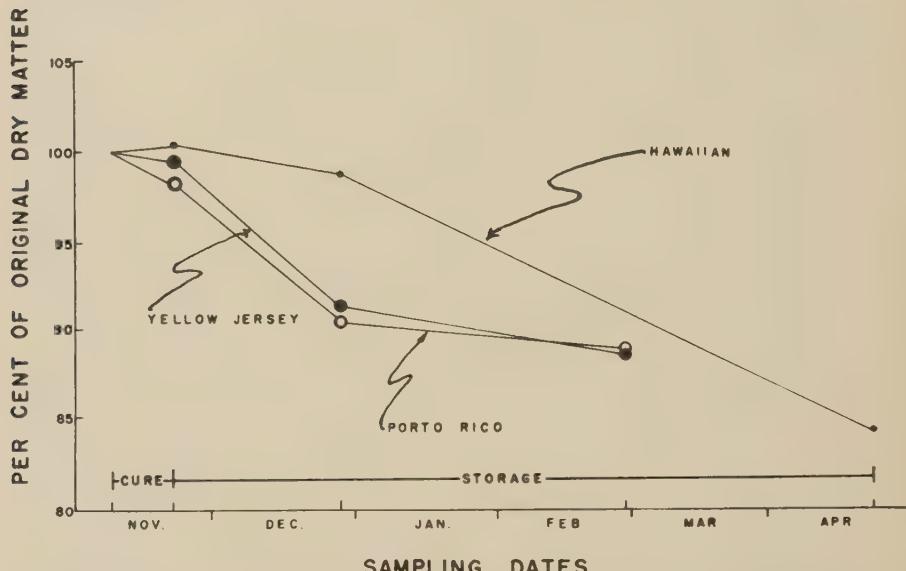


Fig. 4. Dry weight of sweet-potato roots during curing and storage expressed as percentage of dry matter at the beginning of the tests. The graph for each variety represents an average of the three curing methods used. Data from test 1.

Changes in total sugars and sucrose during curing and storage for test 1 are shown in figure 5. On a fresh-weight basis total sugars rose from around 3 per cent at time of harvest to $5\frac{1}{2}$ to $6\frac{1}{2}$ per cent at midstorage. About two thirds of the sugar was sucrose. Total reducing sugars, expressed as invert sugar, showed some increase during storage, and fructose determinations (not shown in fig. 5) indicated that most of the change in reducing sugars was in the fructose fraction. However fructose was always small, the average value for the three curing methods for any variety never exceeding 1 per cent.

Data on sugar analysis for the separate curing treatments are not shown. These data indicate that perhaps the warm-house cure reduced or prevented the accumulation of fructose. Total sugars, sucrose, and reducing sugars expressed as invert showed no large or consistent differences among the three curing treatments.

The data from test 2 are similar except that total reducing sugars and fructose were lower in roots cured in the warm house than in roots cured in the storage house. The reducing sugars showed wide variations and little tendency

to increase during storage. In fact, in the Hawaiian and Porto Rico varieties, the end-of-cure samples showed lower levels of total reducing sugars than did the initial samples.

Refractometer readings were made with a Zeiss hand refractometer on expressed juice from samples used for sugar analysis. Regression of these refractive index values on the total sugar values was significant at the 5 per cent level for each of the varieties in test 1 and at the 1 per cent level for the

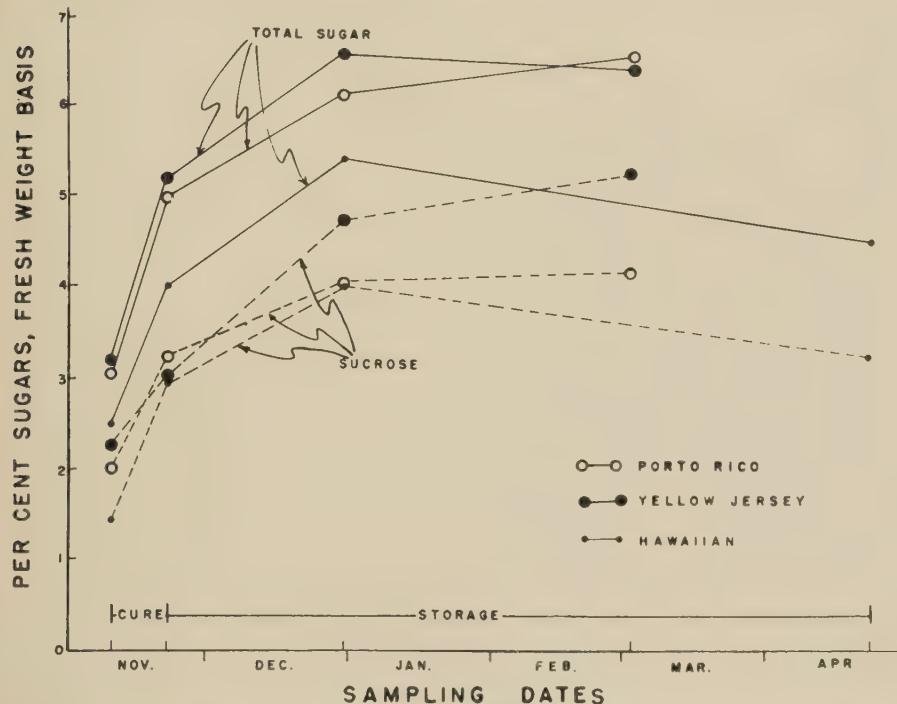
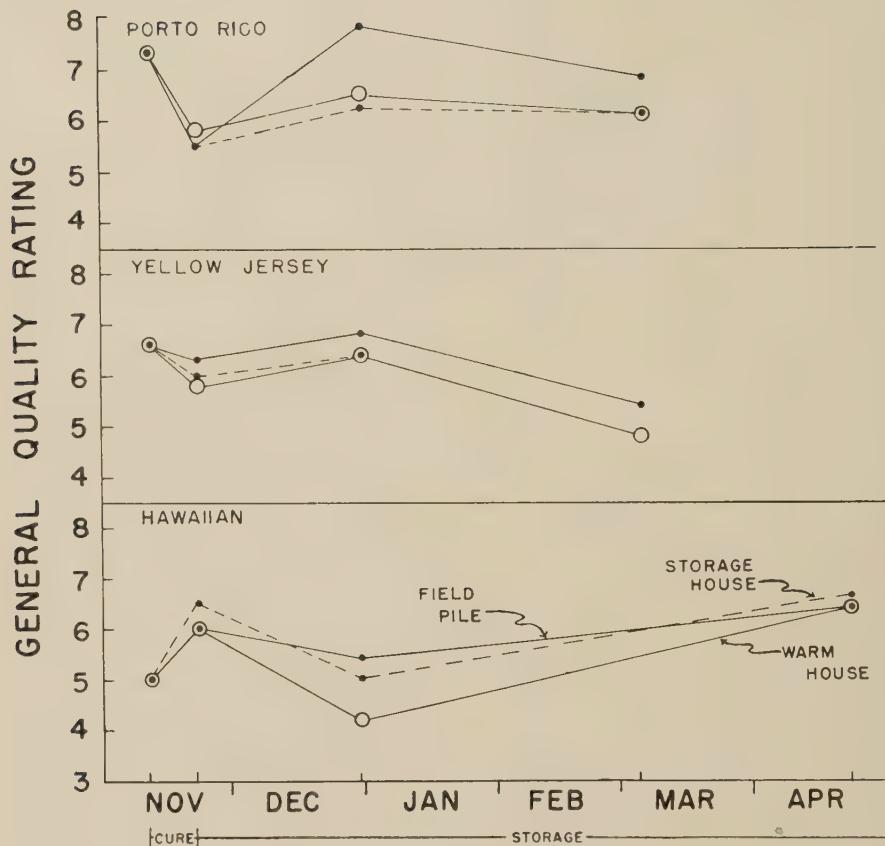


Fig. 5. Total sugars and sucrose of sweet-potato roots during curing and storage, expressed as percentage of fresh weight at the time of sampling. The graph for each variety represents an average of the three curing methods used. Data from test 1.

Porto Rico variety. For the three varieties treated as a single sample, the regression of refractive index on total sugars was significant at the 1 per cent level. However for test 2 the following year, only the Hawaiian variety showed a significant regression (5 per cent level) of refractive index on total sugars, and for all three varieties treated as a single sample the regression was just significant at the 5 per cent level.

It would appear that refractive-index measurements may be of value in estimating total sugar content in sweet-potato roots, but that to be of practical value additional work on technique must be carried out to insure consistently uniform results.

Tasting of boiled roots by five to seven individuals indicated that, within varieties, the curing treatments had little or no differential effect. The average



SAMPLING DATES

Fig. 6. General quality rating of sweet-potato roots during curing and storage as determined by tasting boiled samples. An arbitrary rating scale of 1 to 9 was used, with the highest figure indicating the best quality. Data from test 1.

scores of general quality for test 1 are shown in figure 6. For the Porto Rico and Yellow Jersey varieties the quality was lowered by all curing treatments, but without distinction as to method of curing. In contrast, the Hawaiian showed an increase in quality by the end of the curing period, but again all curing treatments were similar. The Porto Rico was consistently highest in eating quality and the Hawaiian lowest.

The sweetness scores based on tasting showed little or no relation to the sugar content as determined by chemical analysis.

The scores of the boiled samples for moistness of flesh indicated no striking effect of curing treatments, though for all varieties the lots from the storage-house cure were rated most moist. Considering varieties without regard to curing treatment, the flesh of the Yellow Jersey was dry to intermediate and

remained so after curing and throughout storage; the Hawaiians were dry to very dry and became intermediate to moist by the end of storage; and the Porto Ricans, initially intermediate to moist, became moist after curing and throughout storage.

ANATOMICAL OBSERVATIONS

Materials and Methods

Microscopic observations of the periderm during curing and storage were made in test 1 on the Porto Rico, Yellow Jersey, and Hawaiian varieties. All roots required for the periderm samples were selected at the beginning of the test and were subjected to the treatments of the storage test. They were kept in separate containers and each root was discarded after sampling. The samples for study were taken from intact periderm and from two types of wounded areas—the broken end of the potato and a cut surface on the side of the root (fig. 7). Roots showing a smooth, clean break on the end were selected. To simulate a wound on the side of the root, an oval patch of tissue about 1 inch long was removed by a tangential cut with a sharp knife. Except for the initial samples of the broken ends, each sample consisted of 10 blocks of tissue, each from a separate root.

The initial samples, taken November 8 before curing, included only the broken end and the intact side; all subsequent samplings included tissue from the lateral cut surface also. Samples were taken at the end of the curing period (Nov. 22), at midstorage (Dec. 29), and after the completion of the storage period (March 2 for the Porto Rico and Yellow Jersey varieties, April 23 for the Hawaiian variety).

The tissue blocks for sectioning were oblong-rectangular and measured from 3 to 8 mm on a side. These were fixed in Craf 0.30–2.0–10.0 (Sass, 1951), run through tertiary butyl alcohol into paraffin (Johansen, 1940), cut at 15μ , except as noted, and stained with Heidenhain's hematoxylin and safranin O.

As shown in plate 1, the natural periderm and the wound periderm of the sweet potato are similar. Each has a cork layer of storied cells, a cork cambium (which may disappear in the mature periderm), and, beneath the cambium, a phelloderm layer one to three cells in thickness. These latter cells, which are more or less storied, may be derived in part from the cambium and in part from division of cells lying beneath the cambium (plate 3, A).

The wound periderm of roots injured at the time of harvest or later has, in addition to the above tissues, a layer of dead parenchyma exterior to the cork cells (plate 1, B). This layer of surface cells is not passive but, as demonstrated for the white potato by Appel (1906), becomes microchemically distinguishable from the underlying parenchyma soon after wounding and is thought to serve as a barrier to infection prior to the development of cork cells. The macroscopic color and texture of this layer of surface cells is a good indication of the conditions under which wounds have healed. It is thin and light in color when healing is rapid, but becomes thick, dark, and sunken when cork formation is delayed and the wound surface continues to dry. On poorly cured roots this layer renders the wounds conspicuous and unattractive.

While these surface cells are an integral part of the healed wound, plate 1, C, indicates, for injuries occurring in the soil before the roots are dug, that these cells may decay and disappear, exposing the cork beneath. Such a wound periderm resembles the natural periderm in all respects except in its position on the root. In fact, the *natural* and *wound* periderms, as we will use the terms here, differ primarily in that the latter are formed after harvest.

The condition of the periderm was judged by counting the layers of

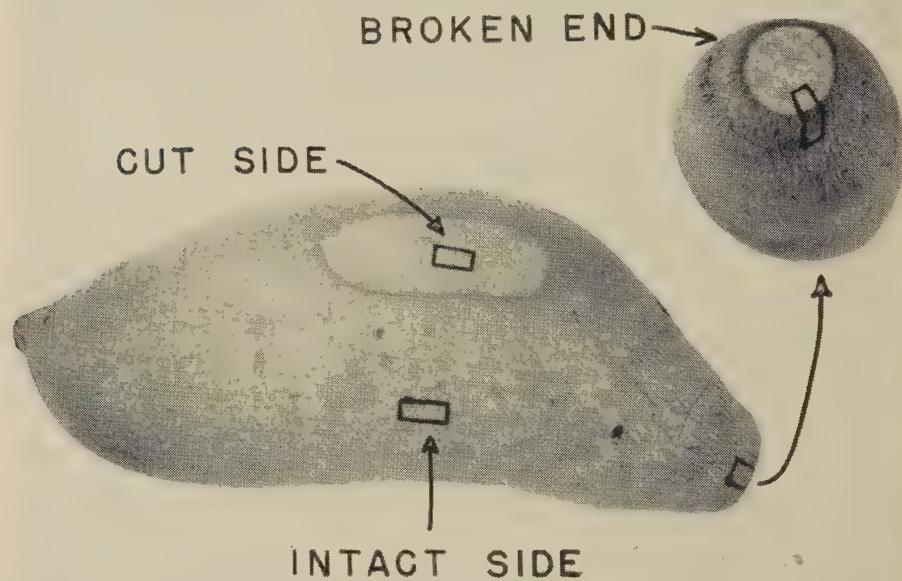


Fig. 7. Position of the periderm samples taken before and after curing and during storage to evaluate changes in the natural (uninjured) periderm and development of the wound periderm.

cork cells on the root surface, or by estimating the activity of the cambium by its appearance and by the presence of immature cork layers, that is, as judged by wall thickness, staining, and cell contents. The cambium and cork are included in a single count, since layers of immature cork cells were difficult to distinguish from the cambial layer. However, for convenience, these counts will hereafter be referred to as *cork layers* rather than cork plus cambium layers. Where there is considerable russetting, as in the Hawaiian variety, there is a great variation in periderm thickness in any one section, and counts were made in areas judged to be of average thickness for the section. The thickness of the whole periderm, that is, including the phellogen, was not used. The latter tissue is of less interest than the cork since it is of doubtful value as a barrier to the movement of water or disease organisms.

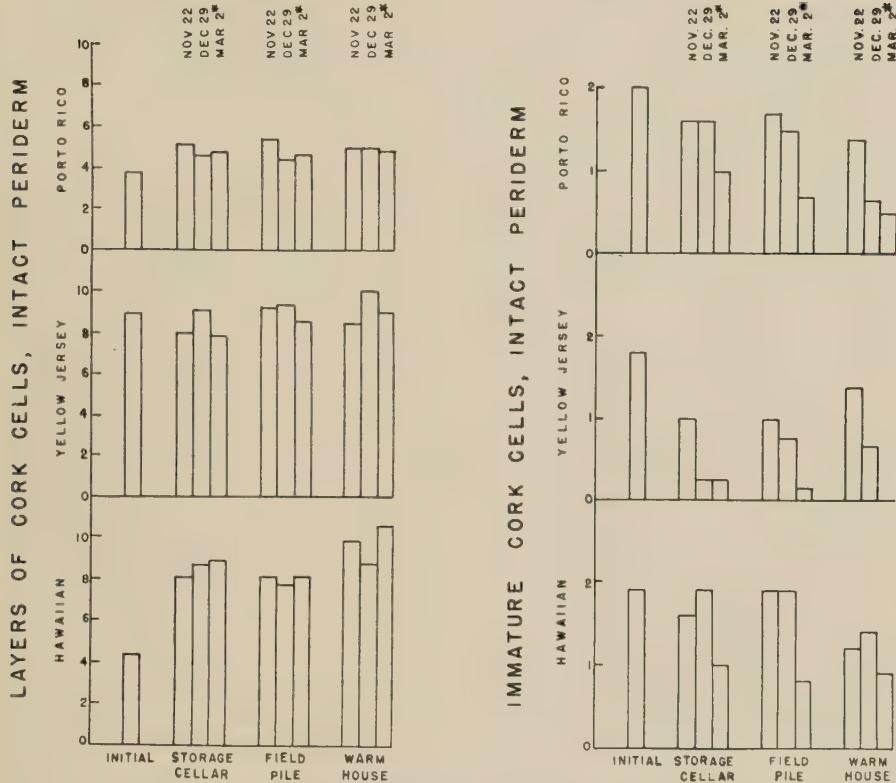


Fig. 8. Changes in thickness of uninjured sweet-potato periderm and in cambial activity during curing and storage. Left graph, layers of cork cells; right graph, cambial activity expressed as relative thickness of immature cork tissue (based on an arbitrary scale—see text). The roots were sampled at the end of the cure (Nov. 22), at midstorage (Dec. 29), and at end of storage (March 2). This last date (*) was April 23 for the Hawaiian variety.

The phellogen is also somewhat variable in thickness and its inclusion would have made the counts less accurate with respect to the cork layer.

Counts were made of the number of layers of dead parenchyma exterior to the wound cork and are used as an indication of the rapidity and effectiveness of wound healing.

Changes in the Natural Periderm during Curing and Storage

Changes in Thickness. The periderm thickness of potato roots growing in the soil may depend on factors such as rate of cork production and loss of surface cork through root enlargement and decay. When roots are placed in storage, the surface loss of cork cells is essentially eliminated and any increase in periderm thickness by addition of cells from the cork cambium may be measured. To get such measurements we made counts of the number of layers of cork and cambial cells in the slides prepared from samples of the intact sides of the roots.

The number of layers of cork comprising the natural periderm for all varieties and treatments is shown in figure 8. Since each of the values given in figure 8 is a mean representing 10 separate roots, those values of particular interest can be compared statistically. All comparisons were made by the *t* test (Snedecor, 1946). The number of cork layers at time of harvest was quite different for the three varieties—about 3.8 layers in the Porto Rico, 9 in the Yellow Jersey, and 5.4 in the Hawaiian variety (fig. 8). These means are all significantly different from one another at the 1 per cent level.

The increase in cork tissue during curing and storage varied with the variety; cork thickness increased on Porto Rico and especially Hawaiian roots but not on Yellow Jersey roots. On the Yellow Jersey roots the thickness of the natural cork was thus independent of the curing process or length of storage period.

On Hawaiian roots the number of cork layers increased significantly after digging for all treatments—in some cases it nearly doubled. Most of this increase occurred during the curing period and was greatest in the warm-house cure. The change that took place during the warm-house cure may be seen by comparing *A* and *B* of plate 2. Some increase in cork thickness on the Hawaiian roots may have continued during storage, at least after the storage-house and warm-house cures. Other evidence to be considered later supports this, but in any case the change was relatively small. For this reason it does not appear objectionable to combine the measurements taken on the three sampling dates into a single mean for each curing treatment. If these means are compared, the roots cured in the warm house had a significantly thicker periderm than those cured in the storage house or in the field pile.

The cork of the Porto Rico variety, though relatively thin, increased only slightly during the curing period and clearly not thereafter. This increase over the initial thickness was statistically significant for all curing methods and was about the same for each.

In summary, the relative number of cork layers of the natural periderm increased during the curing period on the Hawaiian and Porto Rico roots but not on the Yellow Jersey roots. Except, however, for a greater response to the warm-house cure in the Hawaiian variety, these changes during the curing period were about equal for all the curing conditions and should be regarded as postharvest change and not a particular response to curing.

Periderm Changes and Water Loss. The observation that the natural cork tissue of Hawaiian roots is thicker on cured than on noncured roots suggested that curing might bring about a reduced rate of water loss through the natural periderm.

To check this, Hawaiian roots without injury and with moderate and severe surface skinning were studied. The uninjured roots were selected for freedom from skinning and for small wounds at their broken ends. The broken ends were dipped in melted paraffin to reduce water loss from these areas. Moderately injured roots had 10 to 15 per cent of the skin removed by rubbing with a rough cloth, and severely injured roots had 50 to 65 per cent of the skin removed in the same way.

Each of these injury classes was made up of 8 samples of 10 roots each, 4

samples of which were cured and 4 of which were not. The roots to be cured were held for 14 days in a closed box under high humidity in an 80°F room and the noncured lots were held in a 50°F room without humidity control. After curing, all lots were placed in a dark basement room which had little daily temperature fluctuation and remained within the range of 50° to 65° F throughout the experiment. Humidity was not controlled and fluctuated

TABLE 2

WEIGHT LOSS OF CURED AND NONCURED HAWAIIAN SWEET POTATOES
THAT HAD RECEIVED CONTROLLED AMOUNTS OF INJURY TO
THE NATURAL PERIDERM

Treatment	During 14-day curing period per cent	Weight loss for indicated period			
		Days from end of curing			
		6 per cent	13 per cent	61 per cent	164 per cent
No injury:					
No cure.....	1.3	1.1	2.1	4.2	8.9
Cure.....	2.8	0.4	1.0	3.4	7.4
Moderate injury:					
No cure.....	2.3	2.7	4.5	9.6	...
Cure.....	3.9	0.6	1.4	4.0	8.7
Severe injury:					
No cure.....	4.8	13.1	24.6	56.6	66.3
Cure.....	8.5	1.5	2.6	6.9	12.9

from 60 to 95 per cent. The samples were weighed periodically to determine water loss. The weight loss during curing and subsequent storage is shown in table 2.

During the curing period the cured roots lost roughly twice as much weight as did the noncured roots. Thereafter the loss was always greater from the noncured roots, though differences decreased with increasing storage time. Curing was most effective in reducing weight loss where injury was severe.

While these data indicate that curing has its greatest benefits where wounding is extensive, they also indicate that it may reduce weight loss in roots showing little or no visible injury. This conclusion should be applied with caution. If this reduced weight loss depends on a greater thickness of uninjured periderm in cured roots, it would not be observed with the Yellow Jersey variety and would be of little effect with the Porto Rico variety (fig. 8). Even for the Hawaiian variety the differences in periderm thickness, though significant, are not large, so that some effect of curing other than periderm thickness may be involved in this reduction of water loss.

Cork-Cambium Activity and Ease of Skinning. Wounding of sweet potatoes during handling is frequently aggravated by the ease with which the skin slips from the surface of the roots. Newly harvested Hawaiians, for example, skin so readily that injury is hardly avoidable, and this tendency

to skin easily persists to some degree through most of the storage period. Because the presence of an active cork cambium together with thin-walled immature cork cells is generally thought to be associated with skin slipping, these conditions were evaluated from the microscope slides of the natural periderm.

The activity of the cambial region was evaluated for each section by the following rating system: no immature cork = 0; a small amount = 1; a considerable amount (approaching the maximum for any of the samples) = 2. The ratings from each of 10 roots were averaged to give a rating for each sample. Ratings based on the abundance of recently divided cells and the number of layers of cork cells judged to be immature on the basis of wall thickness and staining are necessarily quite subjective, but the differences among certain of the treatments were both conspicuous and consistent. The means for all samples are given in figure 8.

Of the three varieties, the Hawaiian, which had shown the greatest periderm increase following harvest, had a relatively high immaturity value through the midstorage sampling for the storage-house and field-pile cures. The immaturity values were smaller at the final (April 23) sampling for all cures. During the warm-house cure a rapid increase in periderm thickness occurred, but by the end of the curing period the number of immature cork layers was low. The warm-house cure appears to bring about a rapid growth and quick maturity of the cork layers as compared with other curing treatments.

The Yellow Jersey variety, which shows little postharvest change in periderm thickness, had fewer immature cork layers at the end of all curing treatments than at the beginning, and this decrease continued during storage. The Porto Rico variety was mostly intermediate in its immaturity rating compared with the other two varieties.

In general, the cambial activity for all varieties was similar at the time of digging. The number of layers of immature cork decreased with time—rapidly in the Yellow Jersey variety and slowly in the Hawaiian variety. No consistent effects of curing method on rate of cork maturation are evident except for the quicker maturity of the Hawaiian periderm in the warm house.

While only general observations on actual ease of skinning of roots were made on test 1, more detailed records were made the following year on test 3. In test 3, data were taken on the ease of skinning for three varieties and two curing methods. Samples of 10 roots were examined for each date, variety, and treatment. Each root was rated as easy, intermediate, or difficult to skin under thumb pressure. A summary of these ratings appears in table 3.

In this test the rating of "difficult" for the freshly dug Porto Rico roots appears out of line, especially since the cured Porto Rico roots were largely intermediate in their ease of skinning. Except for this inconsistency, the ease of skinning was greatest where the cambium was most active, as indicated by the histological observations of the previous year. The histological observations suggest, for example, that of the three varieties, the Yellow Jersey would be the most difficult to skin at the end of the curing period, and the Hawaiian most easily skinned under all conditions. However, it could

not have been predicted from the histological observations that the skin of the Yellow Jersey and Porto Rico varieties would be more firmly set at the end of the warm-house cure than at the end of the storage-house cure.

Wound Healing during Curing and Storage

Healing of the Lateral Cut Surfaces. Tissue samples for these observations were taken from cut areas on the sides of the roots as indicated in figure 7.

TABLE 3

EASE OF SKINNING (UNDER THUMB PRESSURE) OF THREE VARIETIES OF SWEET POTATOES SUBJECTED TO TWO CURING TREATMENTS

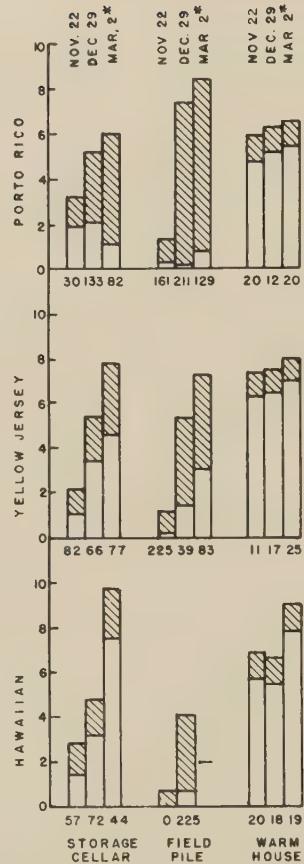
Time of sampling	Curing treatment	Ease of skinning		
		Porto Rico	Yellow Jersey	Hawaiian
At harvest (Oct. 24)....	None	Difficult	Intermediate	Easy to intermediate
After cure (Nov. 6).....	Storage-house cure	Easy to intermediate	Intermediate	Easy
	Warm-house cure	Intermediate to difficult	Difficult	Intermediate
End of storage (April 2). .	Storage-house cure	Difficult	Difficult	Easy to intermediate
	Warm-house cure	Difficult	Difficult	Easy to intermediate

When surface cuts such as these have healed, several layers of parenchyma always remain exterior to the newly formed cork (plate 1, *B*). Under conditions unfavorable to rapid periderm development the surface cells of the wound may dry to a considerable depth, so that a thick layer of dead or partly dead parenchyma is formed. The thickness of this parenchyma exterior to the cork layers is of interest because it is indicative of wound-healing conditions. Its thickness, as well as that of the cork (cork plus cambium), is given in the left-hand graph of figure 9. The following discussion refers to data from this figure.

The Hawaiian roots in the warm-house cure had a well-developed periderm at the end of the two-week curing period. An example of this periderm is illustrated in plate 3, *A*, which shows a near-average section with about 5 layers of cork and about 5 layers of dead parenchyma exterior to the cork. The sections from all 10 roots were quite uniform. Little or no change occurred between November 22 and December 29, but the samples of April 23 showed a uniform increase of about two cells in the cork layer (plate 3, *B*). Since the warm-house cure resulted in the early development of a well-formed wound periderm, the exterior layer of dead parenchyma did not increase during storage.

The Hawaiian roots placed directly into the storage house showed little more than the initiation of a periderm at the end of the curing period (plate 4, *A*). On December 29, average periderm thickness had increased, but two of the sections showed no periderm. On April 23, the average cork thickness was equal to that of the warm-house cure (plate 4, *B*) ; however, the sections were quite variable--one section showed no periderm whatsoever. The aver-

LAYERS OF DEAD SURFACE CELLS AND CORK ON CUT SIDES



LAYERS OF DEAD SURFACE CELLS AND CORK ON BROKEN ENDS

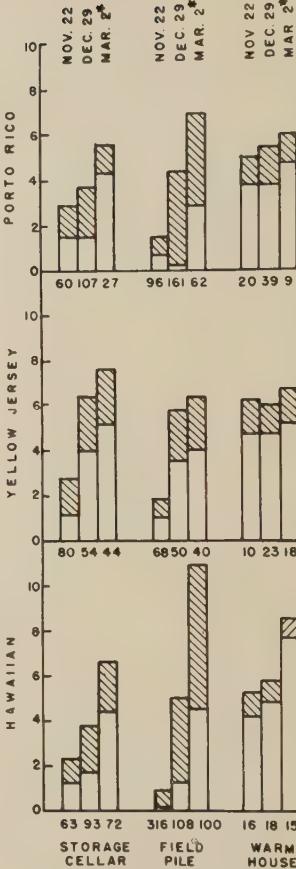


Fig. 9. Changes in thickness of wound-periderm tissues during curing and storage. The number of layers of cork are represented by unhatched areas, the dead cells overlying the cork by hatched areas. For convenience in graphing, the layers of dead surface cells are shown here at one fourth of their actual number. The roots were sampled at the end of cure (Nov. 22), at midstorage (Dec. 29), and at the end of storage (March 2). This last date (*) was April 23 for the Hawaiian variety. The figures beneath the bars are coefficients of variation for the number of cork layers. Left graph, cut sides; right graph, broken ends.

age number of dry surface cells was somewhat greater than that following the warm-house cure; two of the sections showed excessive desiccation.

A section typical of those taken from the Hawaiian variety at the end of the field-pile cure is illustrated in plate 5, A. No wound periderm was in evidence by the end of the two-week cure, and the surface layers showed less drying at this time than they had in other cures, probably because of the combined high humidity and low temperature in the field pile. In roots cured in the field pile, periderm was first seen in 2 of 10 sections from the December 29 sample. Data from the April 23 sections were too incomplete to be of value. All these sections appeared to have periderm, but, except for two samples,

the hard, thick layer of dead surface cells prevented the preparation of satisfactory sections. One of the sections prepared, plate 5, B, illustrates the rather ineffective periderm development, which was hampered by progressive drying of the wound during storage.

The Yellow Jersey and Porto Rico varieties, like the Hawaiian, showed a well-formed and uniform wound periderm at the end of the warm-house cure, but irregular and less satisfactory healing after the storage-house and field-pile cures, especially the latter. The over-all picture of healing in these varieties can be seen from figure 9.

A factor not evident from the mean values given in figure 9 is the variability from root to root in treatments other than the warm-house cure. For example, the Yellow Jersey roots cured in the field pile had formed a cork cambium in only 2 of 10 sections by the end of the curing period. The sample of 10 roots taken at the end of the storage period (March 2) had an average of 3 layers of cork, but actually 4 of the 10 sections still showed little or no periderm formation. Where periderm formation is as variable as this, healing is not satisfactory, and the average values for cork thickness may be misleading—that is, they may suggest better healing than is actually present. To convey the variability of cork thickness the coefficient of variation is shown at the base of each bar in the graph of figure 9.

It is of interest to compare the above data on microscopic structure with the gross appearance of the wounds. Observations on both the lateral cuts and broken ends were taken on all three varieties at midstorage (December 29), 51 days after the start of the cure. The side wounds on the roots from the storage-house and field-pile cures were gray or dark gray and all were sunken, especially those from the field pile. Cracking was observed in some of the thick crusts of tissue over the wounds of the Yellow Jersey and Hawaiian roots cured in the field pile. For both the storage-house and field-pile cures the discoloration and collapse of wound tissue was sufficient to impair the appearance of the roots. In contrast, wounds on roots from the warm-house cure were smooth and almost white. In appearance the broken ends from the storage-house and field-pile cures were similar to lateral wounds except that they were shriveled rather than sunken. Even from the warm-house cure the broken ends showed slight shriveling.

In general, it may be concluded that under conditions favorable to wound healing, a cork layer 5 to 6 cells thick forms at a depth of some 4 to 5 cells beneath the wound surface. This healing takes place quickly, and the new cork forms a continuous and uniform layer. After satisfactory healing there is no change in thickness of dead surface parenchyma and usually little change in total periderm thickness; the wound surface is smooth and nearly white in color.

Healing is usually not satisfactory where cambial development is slow, and even though a thick periderm may eventually form, it tends to be irregular within the wound area and quite variable from root to root. The initiation of such cork layers may take place over a much wider range of conditions than are found necessary for effective wound healing. Wounds that heal poorly tend to be sunken and gray in color.

A comparison of the thickness of the wound cork and the natural cork following the warm-house cure (fig. 9 and left-hand graph of fig. 8) indicates that the wound-cork layers for all varieties are somewhat thinner than the natural-cork layers of the same variety, and further that the wound cork of Porto Rico, like its natural cork, is the thinnest among the three varieties.

Healing of Broken Ends of Roots. Broken ends are of interest because such wounds are present on all potatoes. These wounds differ from the side wounds described above in that the wounded surface is relatively more exposed and severs vascular tissue and laticifers. They differ also in that the surface is irregular, not smooth. Healing of broken ends was studied in the same way as healing of cut sides.

Figure 9 summarizes the data for the broken ends. Comparison of these data with the data given for the cut sides indicates that wound healing in the two areas is essentially alike, and the conclusions about healing of cut sides can be equally well applied to broken ends. Figure 9 shows, for the warm-house cure, that cork thickness increases somewhat toward the end of the storage season. This is most conspicuous in the Hawaiian variety where the cork increases by about one third over its thickness at the end of the curing period. The fact that the final sampling of the Hawaiians was 52 days later than for the other varieties may account for the greater final cork thickness on Hawaiians, though this cannot be determined definitely from the data at hand. For the other varieties the increase, though consistent, is quite small.

A number of the sections of broken ends illustrate quite clearly some of the changes occurring during curing and storage, and these will be briefly described. Plate 6, A, shows a broken end at the conclusion of the field-pile cure. No cork cambium has been initiated and about four layers of parenchyma cells on the broken surface have collapsed. A similar wound at the end of the warm-house cure is shown in plate 6, B. The well-developed wound cork is covered by about four layers of dead surface cells, and the layer of wound cork connects smoothly with the cork layer of the natural periderm on the side of the root. The new cork develops at a fairly uniform distance beneath the wound surface out to the very edge of the wound. This is somewhat contrary to Artschwager and Starrett's (1931) observations on wounds of this type. They state (p. 357) that "near the periphery of the cut root both the suberin layer and the wound periderm are sunk deeply into the tissue beneath the exposed surface." If the healing shown in plate 6, B, followed their observations, the right-hand end of the wound periderm would have formed at a lower level, giving a sloping outline to the new periderm near the wound edge. It seems reasonable that if the wound edges had dried somewhat before curing, a sunken wound periderm would be found near the wound edge, but we have seen no consistent evidence of this in any of our treatments.

Plate 7, A, illustrates unsatisfactory healing in a broken end sampled at the conclusion of the storage period (April 23). This potato had been cured in the storage house and had first formed a periderm which can be seen across the top of the section near the wound surface. This periderm was apparently not effective in healing the wound and a second periderm formed at a much

lower level. Another example of poor healing, shown in plate 7, *B*, is from a root cured in the field pile and sampled at the end of the storage period. The cork here is overlaid by about 15 layers of dead parenchyma cells which would appear to the naked eye as a dark, thick, unattractive crust. In the most extreme section of this sample the crust of dead cells was nearly 90 cell layers in thickness.

Wound-Periderm Formation across Vascular Tissues and Laticifers

When the end of a sweet-potato root is broken off, vascular tissues and laticifers as well as parenchyma are severed. It is not immediately evident how these tissues, among which are the dead tracheary elements and the highly specialized sieve tubes and laticifers, might react to the formation of a wound-periderm layer. To determine what happens when a wound periderm develops, the sections from the broken ends of potatoes cured in the warm house were examined.

Tracheary Elements. These elements vary greatly in size. The largest in the sweet potato are vessel elements approximately 100μ in diameter. The openings these form through the wound surface are large enough to be seen by the unaided eye. The first conspicuous response to wounding on the part of these vessels was the appearance of tyloses within them. Only occasional tyloses could be found in the samples taken at the time of harvest, but in samples taken at the end of the curing period (Nov. 22) tyloses could be found in almost all vessels in the region near the wound surface. This was true for all varieties and for all curing treatments.

Vessels densely packed with tyloses are shown in plate 8, *A*, a section from a Hawaiian root cured in the field pile. These tyloses possess nuclei, divide, and become partly filled with starch so that they resemble the parenchyma surrounding the xylem. In discussing cell division in tyloses, Eames and MacDaniels (1947) suggest that the "multicellular tissue" which fills vessels arises from "multitudes of tyloses, each slender, and all mutually compressed," rather than from cell division among the tyloses. While this may be true for most species, the review of Gertz (1916) indicates that division of tyloses has been observed in a number of plants. In the sweet potato many tyloses may be present in a single vessel element, but these tyloses also divide. The divisions may be sufficiently frequent to affect the appearance of the tissue filling the vessel lumina (plate 8, *A*; 9, *A* and *B*).

This ability of the tyloses to divide is carried even further when a wound periderm forms across vessels. Plate 8, *B*, from a Hawaiian root cured in the warm house, demonstrates that tyloses may take part in periderm formation, producing quite typical cambium and cork layers across the lumina of the elements. This type of healing has been observed in the three varieties studied.

Sieve Tube Elements and Laticifers. These structures, like the xylem elements, are fairly large in sweet potatoes. They differ from the xylem elements in several ways, but their possession of relatively thin nonrigid walls appears to be of most importance in their behavior toward the wound periderm. A healed wound in which the periderm layer crosses a sieve tube is shown in plate 10, *A*, and a well-formed periderm crossing a laticifer is shown

in plate 10, *B*. Both the sieve tube and the laticifer collapse or are pinched off, and the periderm layer becomes continuous across the region they occupied. As indicated in plate 10, *B*, the laticifers collapse only in the region of the periderm and retain their usual size a short distance beneath the periderm. The sieve tubes, on the other hand, usually collapse for a distance of several consecutive elements beneath the periderm. Laticifer collapse was observed in the Porto Rico and Yellow Jersey varieties and sieve tube collapse in all three varieties.

DISCUSSION

The observations on curing and storage recorded here agree well with those from similar tests in other areas (Lutz and Simons, 1948). In our tests no attempt was made to evaluate methods of curing beyond comparing a recommended curing treatment with local practices which were suspected of being ineffective, or even harmful. No attempt was made to determine optimum temperatures, times, or humidity levels for curing. A recent study by Lutz (1952) indicates that a curing period as short as four days at 84° F is adequate.

Our general conclusion from these tests would be that where storage of sweet potatoes for several months is economically sound, curing will usually reduce rot, improve the appearance of the roots, and decrease handling and sorting at the end of storage. It should be emphasized, however, that part of the apparent benefit of the warm-house cure, as compared with the field-pile cure, may have resulted from the harmful effects of low temperature, that is, chilling injury, during the field-pile curing period.

Of the three varieties used in the tests, the Yellow Jersey benefited least from curing. In the first test this variety was known to be heavily infected with black rot, and in the later tests it was probably more heavily infected than were the other varieties. Black rot is not controlled by curing and where prevalent it would be wise to market the potatoes without storage.

Weimer and Harter (1921) and Artschwager and Starrett (1931) have reported in some detail the effect of environmental factors on periderm formation in the sweet potato. Their studies were mostly limited to laboratory tests of relatively brief duration (the curing period) and to the wound periderm only. In the present tests no attempt was made to evaluate the environment beyond the three rather divergent curing treatments used, but the healing of wounds was followed throughout the storage period, and changes in the natural periderm were observed as well.

Observations on the healing of wounds formed by slicing tissue from the side of a root with a sharp knife show that these heal in a fashion almost identical to that of broken ends. This suggests that the most carefully handled roots respond to curing in the same fashion as do more severely injured roots. Weimer and Harter's (1921) observation that bruise wounds heal less readily than exposed cuts suggests that a study such as that made here on cut sides and broken ends should be extended to bruises.

SUMMARY

Storage losses and quality changes were observed in five sweet-potato curing and storage tests on farms in the San Joaquin Valley. These tests were

conducted over a period of four years and included three prestorage treatments, designated as field-pile, storage-house, and warm-house cures, applied to the Yellow Jersey, Porto Rico, and Hawaiian varieties.

The anatomy of the natural periderm and of wound periderms formed on broken ends and over lateral knife wounds was studied during curing and storage in one of these tests.

Potatoes given the field-pile cure were placed in piles in the field and covered with paper and sweet-potato vines; those receiving the storage-house cure were placed directly in the unheated storage in which they were to remain until marketed; and those given the warm-house cure were held in heated rooms with high humidity. However, the conditions of the latter cure varied widely. The cures lasted about two weeks after which the potatoes from the field pile and warm house were placed in storage.

The warm-house cure, as compared with the other curing methods, yielded significantly more marketable potatoes in 7 of 10 comparisons for the Porto Rico variety, in 3 of 8 for the Yellow Jersey, and in 7 of 8 for the Hawaiian. In no instance did the warm-house cure result in significantly fewer marketable potatoes at the end of the storage period.

Weight loss from evaporation and respiration over the entire storage period was not generally reduced by the warm-house cure, but rot loss, which includes all loss not accounted for by weight loss, was markedly reduced by the warm-house cure except in some tests on the Yellow Jersey variety. Rot losses were particularly high for roots cured in the field pile. The fact that roots stored in the field pile may have suffered low-temperature injury (chilling injury) must be considered.

Dry weight, as percentage of fresh weight, showed little change from the time of harvest to the end of the storage period. Loss of dry weight was not influenced by curing treatment except near the end of the storage period, when loss from roots cured in the warm house was greatest for all varieties, and was undoubtedly associated with the heavy sprouting in this treatment.

Total sugars, as percentage of fresh weight at time of sampling, approximately doubled from harvest to midstorage in all three varieties, but there were no large or consistent differences among the curing treatments. About two thirds of the sugar present was sucrose. Hand-refractometer readings were indicative of sugar content but were not sufficiently uniform to be of practical use.

The natural uninjured periderm on the side of the roots increased markedly during the curing period in the Hawaiian variety, and this increase was greatest for the warm-house cure. Storage tests indicate that the increase attributable to curing may slightly retard water loss. The intact periderm of the Porto Rico variety also increased during curing, but that of the Yellow Jersey did not. For none of the three varieties did the intact periderm increase to any extent during the storage period that followed the cure.

In the warm-house cure, both types of wounds studied developed a layer of cork mostly 5 to 6 cells thick, covered by a layer of 4 or 5 dead parenchyma cells. These wounds were light in color and changed little in macroscopic appearance throughout subsequent storage. Wound healing was less satisfac-

tory during the storage-house and field-pile cures, particularly the latter. Poorly healed wounds continued to form irregular and ineffective layers of cork during subsequent storage, and the wound surface dried out and became depressed, dark, and unattractive.

During wound healing of the broken ends of roots, sieve tubes and laticifers are compressed and pinched off in the region of the wound periderm. Vessel elements become filled with tyloses in the wound area, and these may divide to produce a cork layer across the vessel lumen, continuous with the surrounding wound cork.

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LITERATURE CITED

- APPEL, OTTO**
 1906. Zur Kenntnis des Wundverschlusses bei den Kartoffeln. Deut. Bot. Gesell., Ber. 24: 118-122.
- ARTSCHWAGER, ERNST, and RUTH COLVIN STARRETT**
 1931. Suberization and wound-periderm formation in sweetpotato and gladiolus as affected by temperature and relative humidity. *Jour. Agr. Res.* 43: 353-364.
- ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS**
 1945. Official and tentative methods of analysis of the Association of Official Agricultural Chemists. 6th ed., p. 133-134. Washington, D.C.
- BROWN, H. D., and CHESTER S. HUTCHISON**
 1949. Vegetable science. 452 p. J. B. Lippincott Co., New York, N.Y.
- EAMES, ARTHUR J., and LAURENCE H. MACDANIELS**
 1947. An introduction to plant anatomy. 2d ed., 427 p. McGraw-Hill Book Co., Inc., New York, N.Y.
- GERTZ, OTTO**
 1916. Untersuchungen über septierte Thyllen nebst anderen Beiträgen zu einer Monographie der Thyllenfrage. Lunds Univ. Årsskr. N. F. Avd. 2 12(12): 1-45.
- JOHANSEN, DONALD ALEXANDER**
 1940. Plant microtechnique. 523 p. McGraw-Hill Book Co., Inc., New York, N.Y.
- KIMBROUGH, W. D., and M. F. BELL**
 1942. Internal breakdown of sweet potatoes due to exposure to cold. Louisiana Agr. Exp. Sta. Bul. 354: 1-9.
- LAURITZEN, J. I.**
 1931. Some effects of chilling temperatures on sweetpotatoes. *Jour. Agr. Res.* 42: 617-627.
 1935. Factors affecting infection and decay of sweetpotatoes by certain storage rot fungi. *Jour. Agr. Res.* 50: 285-329.
- LONG, J. D., and D. R. PORTER**
 1940. Sweet potato storage studies. California Agr. Exp. Sta. Ann. Rept., p. 166-218. Project 947. (Unpublished.)
- LUTZ, J. M.**
 1945. Chilling injury of cured and noncured Porto Rico sweetpotatoes. U. S. Dept. Agr. Cir. 729: 1-8.
 1952. Influence of temperature and length of curing period on keeping quality of Porto Rico sweetpotatoes. Amer. Soc. Hort. Sci. Proc. 59: 421-425.
- LUTZ, J. M., and J. W. SIMONS**
 1948. Storage of sweetpotatoes. U. S. Dept. Agr. Farmers' Bul. 1442: 1-50.
- MINGES, P. A., and L. L. MORRIS**
 1953. Sweet potato production and handling in California. California Agr. Exp. Sta. Cir. 431: 1-38.
- SASS, JOHN E.**
 1951. Botanical microtechnique. 2d ed., 228 p. Iowa State College Press, Ames, Iowa.
- SNEDECOR, GEORGE W.**
 1946. Statistical methods. 4th ed., 485 p. Iowa State College Press, Ames, Iowa.
- THOMPSON, HOMER C.**
 1949. Vegetable crops. 4th ed., 611 p. McGraw-Hill Book Co., Inc., New York, N.Y.
- THOMPSON, H. C., and JAMES H. BEATTIE**
 1922. Group classification and varietal descriptions of American varieties of sweet potatoes. U. S. Dept. Agr. Bul. 1021: 1-30.
- WATTS, RALPH L., and GILBERT SEARLE WATTS**
 1939. The vegetable growing business. 549 p. Orange Judd Publishing Co., New York, N.Y.
- WEIMER, J. L., and L. L. HARTER**
 1921. Wound-cork formation in the sweetpotato. *Jour. Agr. Res.* 21: 637-647.
- WORK, PAUL**
 1945. Vegetable production and marketing. 559 p. John Wiley and Sons, Inc., New York, N.Y.

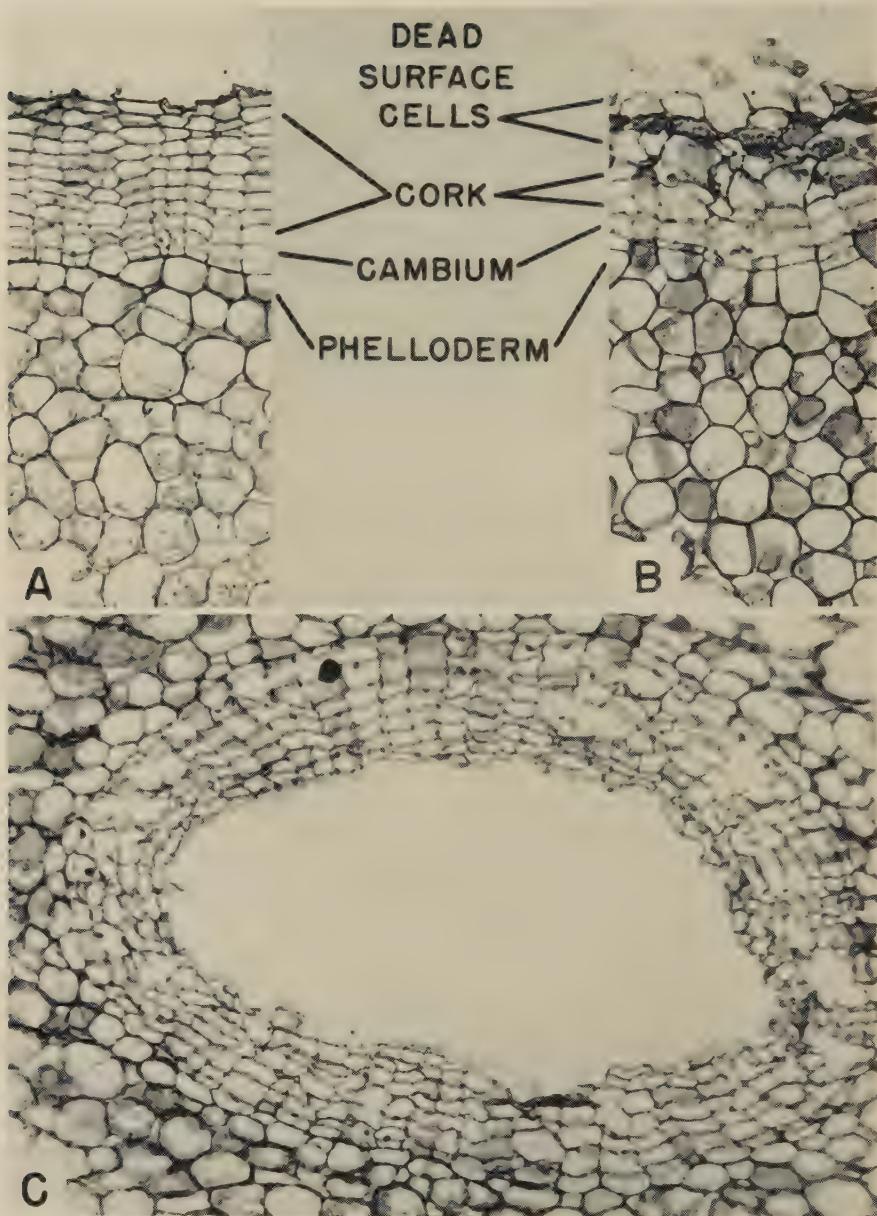


Plate 1. Examples of natural and wound periderm in the sweet-potato root: *A*, natural periderm; *B*, wound periderm from a cut surface; *C*, wound periderm around a wireworm hole. The only qualitative difference between *A* and *B* is the presence of dead cells exterior to the cork in *B*. The wound at *C*, made before harvest, has come to resemble the natural periderm at *A*. Hawaiian variety ($\times 77$).

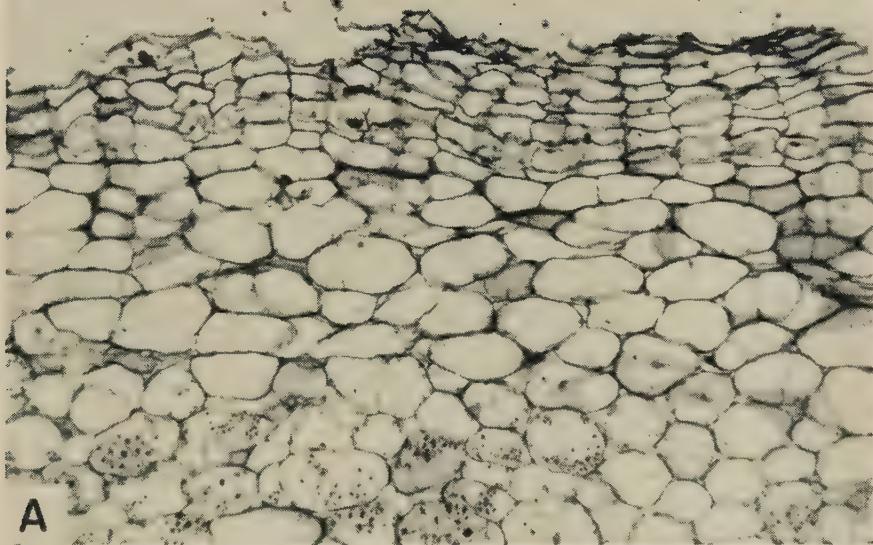
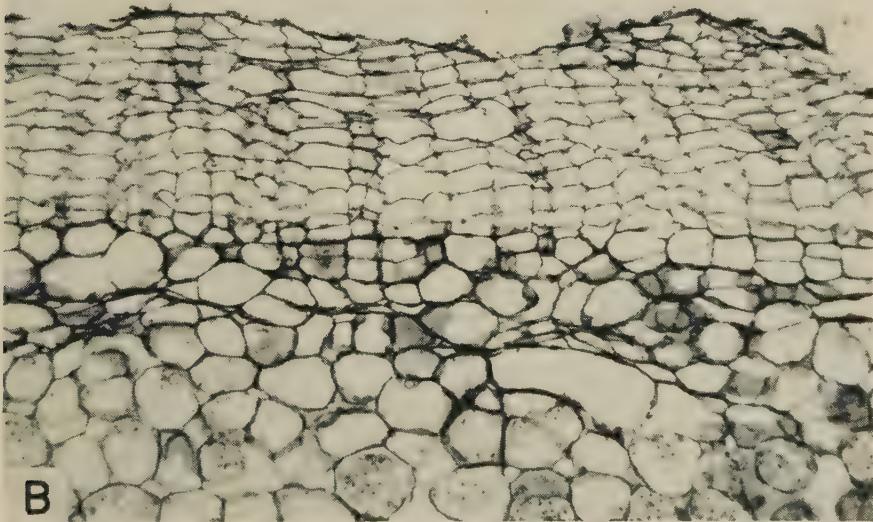
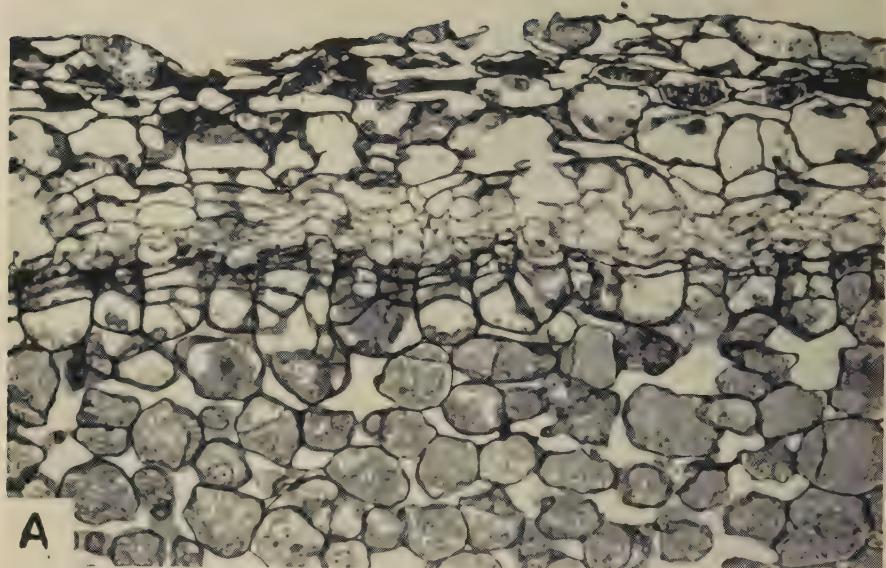
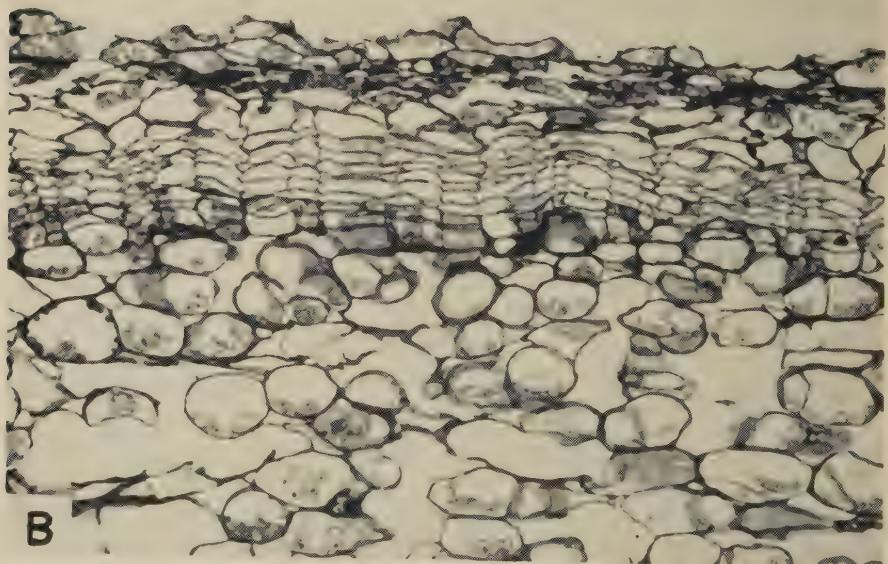
**A****B**

Plate 2. Increase in thickness of the natural periderm during curing: *A*, periderm on the side of a root at time of harvest (Nov. 8); *B*, similar periderm at the end of the warm-house cure (Nov. 22). In both *A* and *B* the cork layers are slightly thicker than the average of the sample they represent (compare fig. 8). Hawaiian variety ($\times 77$).



A



B

Plate 3. Wound periderm before and after storage following the warm-house cure: *A*, cut side at end of curing period (Nov. 22); *B*, cut side at end of storage period (April 23). In both *A* and *B* the number of layers of dead surface cells is about average for the sample, and the number of layers of cork is about one layer below average (compare fig. 9). Hawaiian variety ($\times 77$).

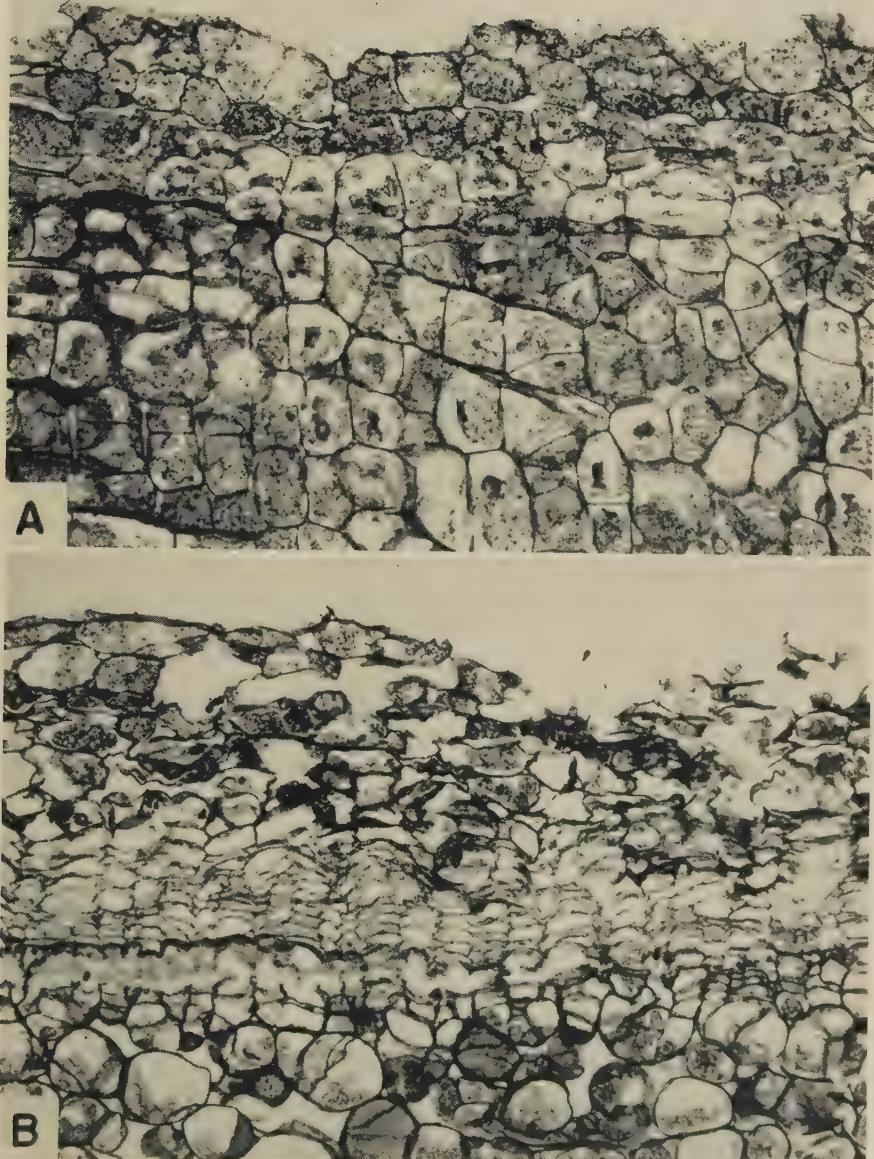


Plate 4. Wound periderm before and after storage following the storage-house cure: *A*, cut side at end of curing period (Nov. 22), showing an early stage of periderm formation; *B*, cut side at end of storage period (April 23). Both *A* and *B* are about average but represent quite variable samples (compare fig. 9). Hawaiian variety ($\times 77$).

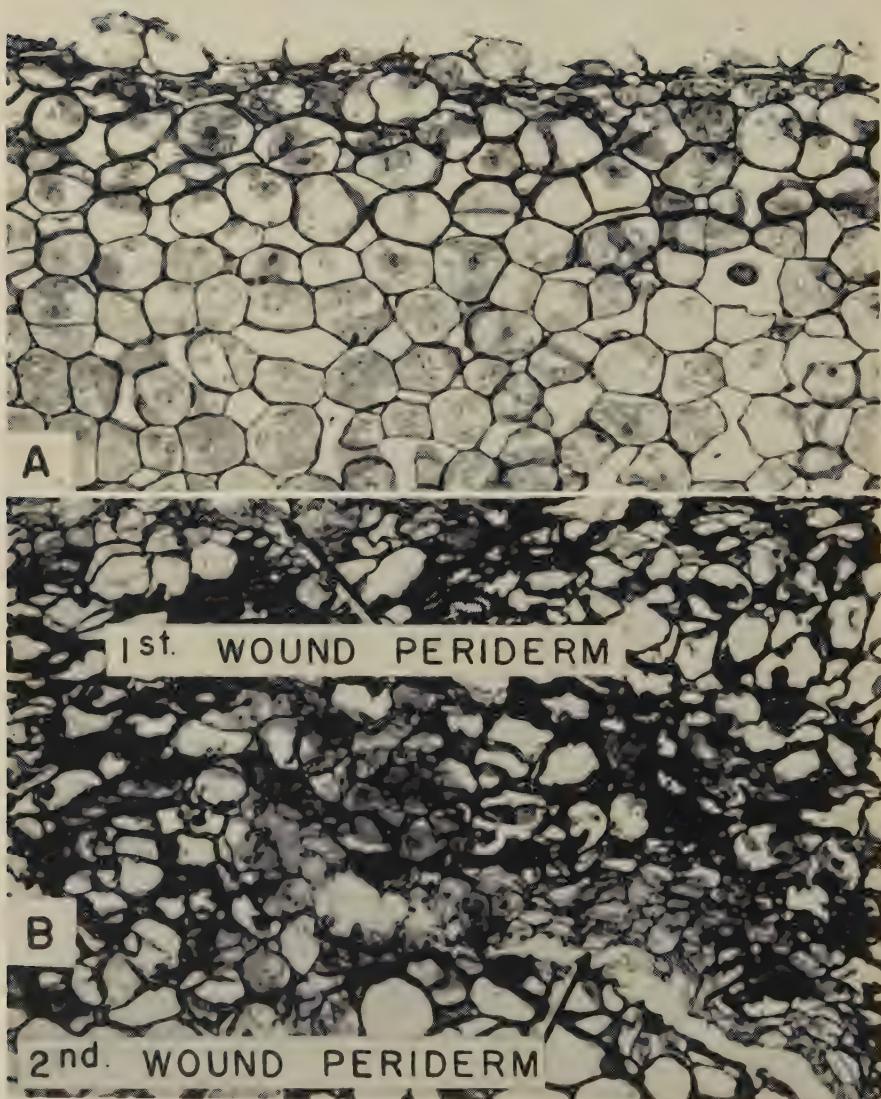


Plate 5. Wound periderm before and after storage following the field-pile cure: *A*, cut side at end of curing period (Nov. 22); *B*, cut side at end of storage period (April 23). No sections of the sample from which *A* was taken showed periderm development. In *B* the wound surface is above the top of the picture. The first periderm formed is dead, and a second, incomplete periderm has formed below (compare fig. 9). Hawaiian variety ($\times 77$).

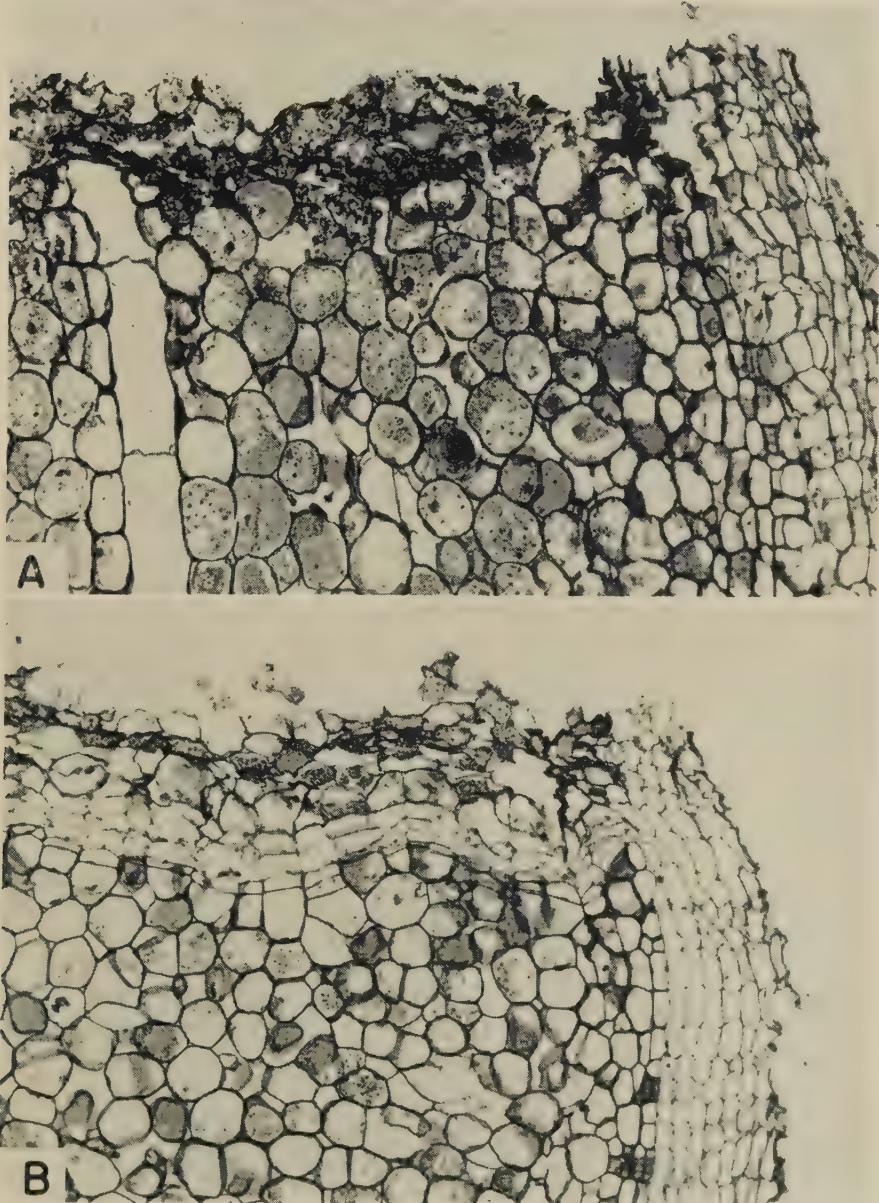


Plate 6. Wound healing on broken ends of sweet potatoes at end of curing period: *A*, after field-pile cure (Nov. 22); *B*, after warm-house cure (Nov. 22). Both are about average for the samples they represent (compare fig. 9). Note the laticifer at the left in *A* and the connection of the wound cork and natural cork in *B*. Hawaiian variety ($\times 77$).

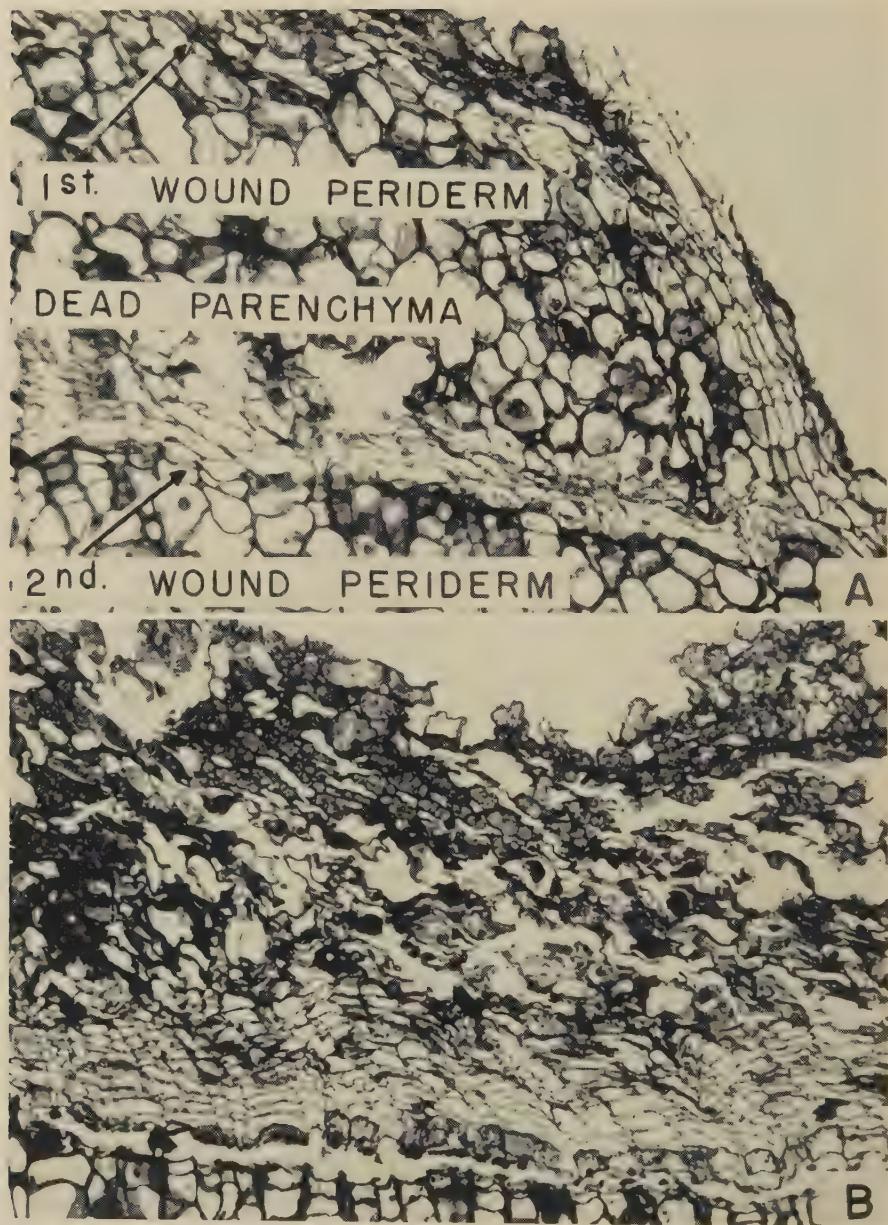
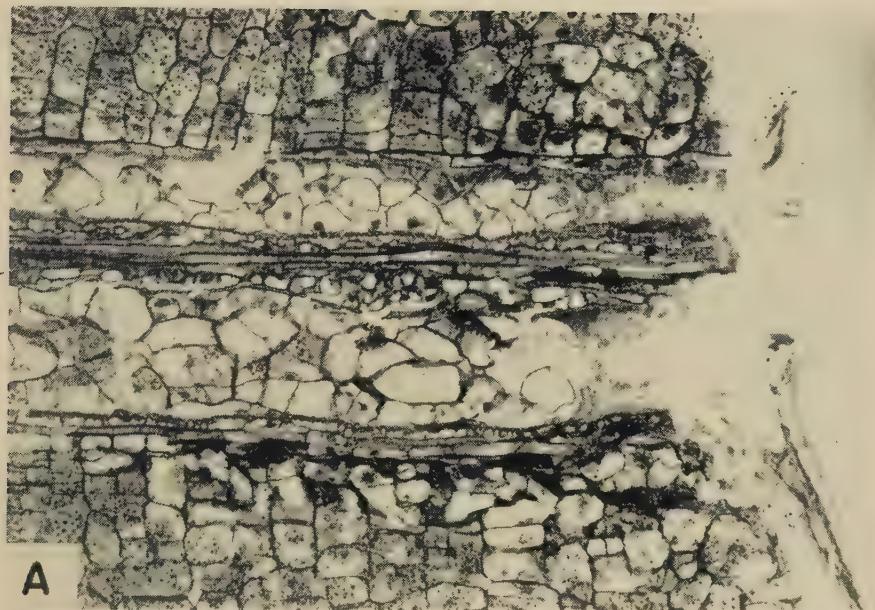


Plate 7. Ineffective wound healing on broken ends of sweet potatoes. *A*, at end of storage period (April 23) after the storage-house cure, showing the presence of two wound periderms. *B*, at end of storage period (April 23) after the field-pile cure. There are about 15 layers of dead surface cells here; the extreme section of this sample had about 90 layers (compare fig. 9). Hawaiian variety ($\times 77$).



A



B

Plate 8. Tyloses in vessel elements of wounded sweet-potato roots. A, broken root-end at the conclusion of the field-pile cure. The broken end (at the right) shows little evidence of periderm initiation. B, broken root-end at the conclusion of the warm-house cure, in which the tyloses have given rise to a wound periderm across the lumen of a tracheary element. Hawaiian variety ($\times 77$).

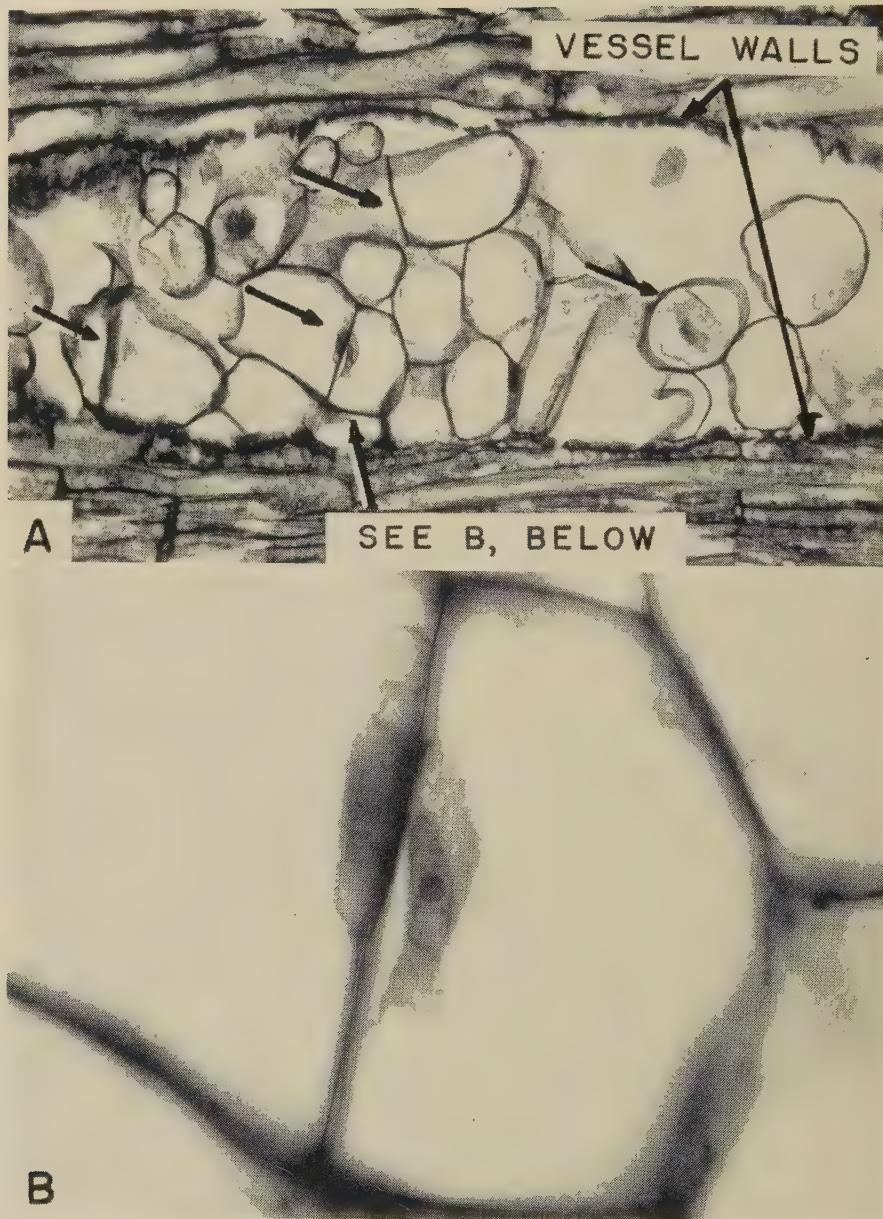


Plate 9. Division of tyloses within vessels. *A*, the tyloses here are relatively uncrowded; four new walls where tyloses have divided are indicated by arrows. *B*, portion of a recently divided cell from *A*, showing wall and nuclei at greater magnification. Yellow Jersey variety (*A* $\times 215$; *B* $\times 1,260$).

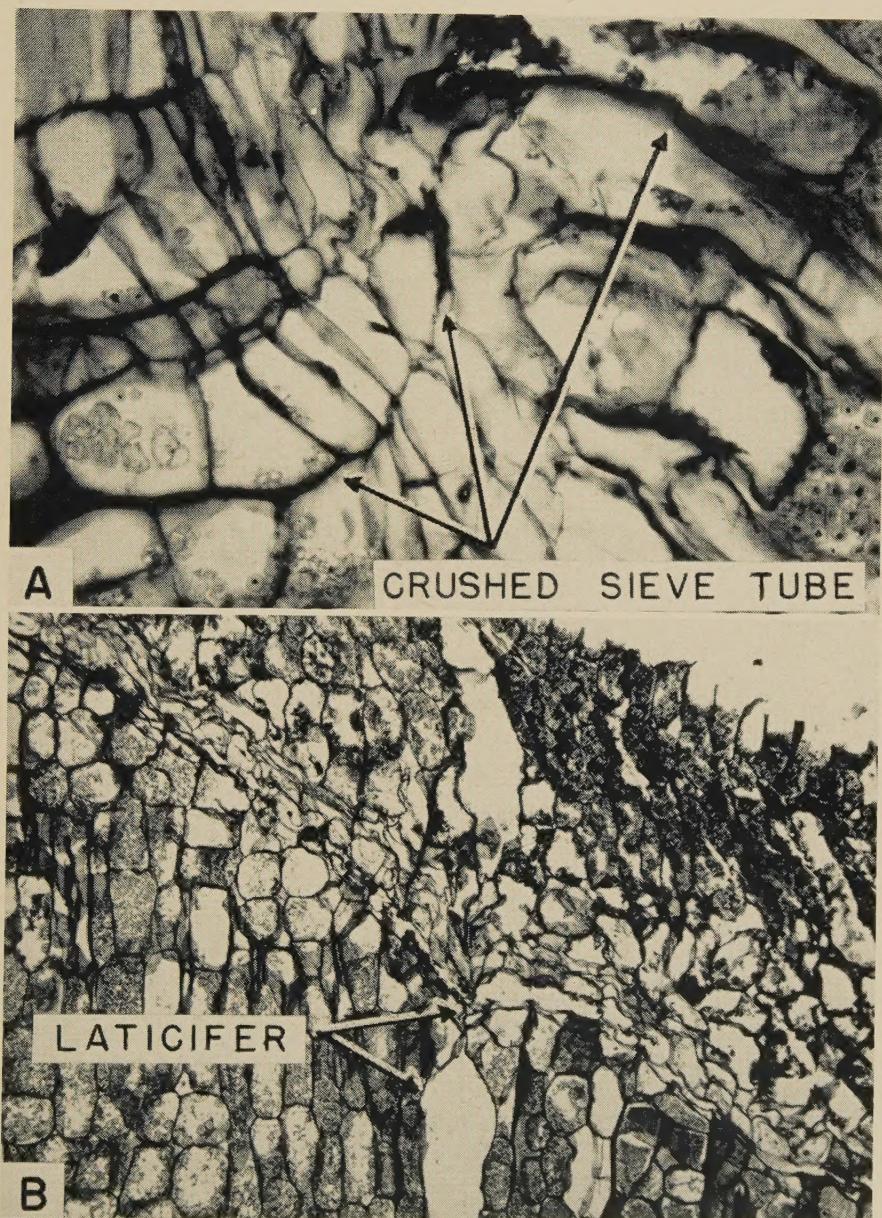


Plate 10. Wound healing across sieve tubes and laticifers of sweet-potato roots. *A*, wound periderm across a sieve tube of a Yellow Jersey root. The wound surface lies to the right. The sieve tube, indicated by the arrows, has been crushed and torn apart by the periderm. *B*, laticifer that has been collapsed by the formation of a wound periderm across the broken end of a Porto Rico root. (*A* $\times 300$; *B* $\times 77$).

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